MASTER THESIS

TITLE: Power system optimisation for a fixed-wing UAV with VTOL capability

MASTER DEGREE: Master's degree in Applications and Technologies for Unmanned Aircraft Systems (Drones) (MED)

AUTHOR: Amr Aldroubi

ADVISOR: Miguel Mulet

SUPERVISOR: Xavier Prats

DATE: September 6, 2018

TITLE: Power system optimisation for a fixed-wing UAV with VTOL capability.

MASTER DEGREE: Master's degree in Applications and Technologies for Unmanned Aircraft Systems (Drones) (MED)

AUTHOR: Amr Aldroubi

ADVISOR: Miguel Mulet

SUPERVISOR: Xavier Prats

DATE: September 6, 2018

Abstract

This thesis is focused on optimising a power system for a fixed wing aircraft with VTOL (Vertical takeoff and landing) capability. This aircraft is meant to be used in various industrial sectors such as (such as agriculture, Oil, gas, electricity, trains. etc) for surveying and maintenance aspects. The aircraft can be equipped with any kind of sensors suitable for the mission. The dual capability of the drone reduces the consumption of power as it uses only one motor (the cruising motor) during the mission and the VTOL for ease of take-off and landing. Prior to the mission, the desired sensor will be attached to the aircraft, the desired way points will be defined using a ground control station, the aircraft will take-off vertically to a certain height then do a transition from the VTOL motors to the cruising motor, do the mission and land again at the starting point.

The thesis presents all components involved in building up and optimising the power system of the aircraft such as batteries, ESC's, motors and propellers. The motor-propeller combination was chosen based on a static and dynamic tests to get the highest efficiency with minimum power consumption. The hardware and software choices are combined into a system and implemented on the aircraft. The aircraft has 5 motors, 4 for the VTOL and one cruising motor, controlled by 5 ESC's. Lithium-ion batteries are used to power up the aircraft so it will be fully electrical. The power optimisation takes in consideration the aerodynamics of the aircraft. In this thesis a multiple static and dynamic tests were done for the motors/propellers combinations and the results were promising, as will be discussed in details in the upcoming chapters . After performing a static and dynamic tests, the chosen motor is Q80 Hacker motor with 24x12 wood propeller as this combination gives the required thrust that the aircraft needs to fly and operate safely. Some improvements still needs be done in the future for the testing procedures and the method of collecting the data.

Acknowledgements

A special thanks to the masters director Dr. Miguel Valero for all his support during all the stages of the master.

I would also like to thank my academic supervisor Dr.Xavier Prats for his support and monitoring along the thesis.

This work conducted in this thesis is done in cooperation with Venturi Unmanned technologies. I would like to thank Ventury Unmanned Technologies for their hospitality, providing me the work place and supplying all materials needed for my project.

Amr Aldroubi

Contents

List of Figures

List of Tables

Introduction

Unmanned Air Vehicles (UAV's) are and have been prominent to use in several governmental and industrial sectors. As in the past it was mainly used in the military but nowadays it's been highly used in the civil applications. As the technology is becoming more and more advanced, the use of drones is becoming more convenient and cost less as drones nowadays are replacing humans, helicopters and aircraft in several applications mainly in inspection, surveillance, surveying, search and rescue and even providing first aid when there is an accident. Autopilot replacing a human being has a lot of benefits as it reduces the cost of a mission and it saves human lives. For example, speaking about inspection, to inspect a hundred of kilometres of oil and gas pipelines , companies uses a helicopter and at least 2 persons to do the job and that is an expensive job considering pilots salaries, the rental of the helicopter and the fuel, the same is applicable for surveying and agriculture crops monitoring. Using UAV's in the industry will push the industry forward.

As the main issue nowadays is the flight time, most of the drones now can fly between 15-40 minutes. Providing a drone that able to fly 2-3 hours will be more functional and reliable. Using only one motor while cruising with the aid of the aerodynamic design of the aircraft reduces power consumption significantly along with increasing the flight time. Choosing the right motors/propeller combination for your aircraft is very important to reach the maximum flight efficiency and to be able to fly smoothly with no extra load on any components. To do so several static and dynamic tests will be performed in this thesis to choose the perfect combination and implement it on the aircraft.

During the last years, there has been an exponential growth in the aircraft sector. However, one of the main technology drawbacks is limited flight time. In the case of malty-rotor, lasting around 20 minutes. Fixed-wings can fly longer, but a runway is needed to operate. Plus, current work flow is time-consuming, consisting of gathering data with sensors and computer post-processing. As a first product, a Vertical Take-Off and Landing (VTOL) aircraft will be launched. This does not require any runway or launching system. This aircraft will be offered in tow different models, an electric and a hydrogen power system. By using hydrogen powered systems, flight time is extended up to 8 hours, offering the largest endurance in its class. Moreover, on-board analytic software will be integrated, avoiding time-consuming post-processing. This thesis aims to design and implement the electric power system of this aircraft,as it consist of 5 motors in total one for cruising and four for VTOL system.

Chapter 1. Background and related work

1.1 Oil and Gas

Oil and gas sectors traditionally use a ground vehicle just like cars and manned air crafts (fixed wing or helicopters) to detect damages and future threats to pipelines along hundreds or thousands of kilometres. The estimated amount of money that is been spent in this sector is about 50 billion dollars annually. Furthermore, The frequency of pipeline survey from the air depends on the size of the pipeline and its contents, is more often than not regulated. some of the pipelines need surveillance every day and some every month or every 6 months, such inspections are very costly and time-consuming. The data analyzing in the other hand that is collected from varies sources is another challenge. Drones nowadays are sufficient enough to be used in pipeline operations like conducting surveying and mapping of the pipeline during the rout planing process[1]. Drones could prove to be an effective alternative especially for remote and hard to reach areas. Drones are also used to conduct a thermal inspection of the pipelines to detect leaks, and that is performed using thermal imagining due to the difference in temperature of the oil or gas and the surroundings. Furthermore, drones are being used to detect structural damages, vegetation growth and other problems associated with the pipeline. It provides more flexibility as they can be programmed to cover large areas in a systematic way while providing also easy reach for difficult to reach areas. Nevertheless, drones are proved to be an economical solution in this area.

1.2 Agriculture

Drones equipped with a malty-spectral imaging sensor are changing the rules of the game for the agriculture industry. Many years before this type of sensors was very large and can be fitted only on a manned aircraft to be flown over the crops area, this method is extremely costly and expensive so it could be done few times per year. Nowadays with the drones and compact sensors, farmers theme selves could pilot the drone and scan their crops as much as they want to detect any injured crops or to locate any infected parts of crops, as this procedure cost a small fraction of the previous cost. Furthermore, drones can do detailed maps of the crop field using GPS along with their onboard mounted camera, this process can help farmers to plan and organize their crops for better use of the land area and saving irrigation water[2]. On the other hand, heavy lift drones could be able to lift tanks full of fertilizers or pesticide and spray all the crops. Not only crops could be surveyed and checked but also the animals in the farm, with a thermal imaging camera equipped on a drone, livestock could be monitored and checked if there any injured, missing or berthing animals. As machine learning and drones efficiency are improving drones are the future of the agricultural farming sector.

1.3 Inspection

The number of drones used for visual inspection is increasing day by day, as its cost-conscious and effective way to inspect heights and inaccessible areas[3]. Drones can be used to inspect power lines and power pylons for bird's nests. lightning strikes, rust, corrosion and damaged bolts using a thermo-graphic or a high-resolution camera. Not only it cut the costs and time along with decreasing injuries, with drones inspection companies can obtain high-quality detailed images of overhead utility lines to look for damages. Moreover, they can provide real-time data, images, and post-inspection analysis. Drones also can be utilized for post-storm investigations or being on hand to spot test transmission lines as they can also get much closer to infrastructure than helicopters, and have superior mapping and surveying capabilities, high-quality sensors and high-resolution cameras which helps to reduce labor-intensive undertakings for work crews.

1.4 Mining

sing drones in mining will allow capture of 3D spatial data in difficult to reach the underground area in mines so it eliminates the hazard and danger that could a human face. Drones usage in mining for underground mapping has a variety of other benefits as being cost effective and easy on labor. Some companies nowadays are developing a 3D mapping system capable of building 3D maps in real time without the need for the GPS signal for positioning aspects[4]. A 3D laser area scanner can perform the underground mapping that is light enough to be carried in the drone. Other uses of drones in mining :

- Inspection
- Surveying
- 3D profiling
- Vehicle positioning
- Large area 3D scanning
- 3D mapping

The drone use in underground mining has promising benefits, especially for keeping people safe outside of underground mining and remote areas. Drones in a mining environment are projected to have a major impact on the industry in the fields of productivity, cost-effectiveness, safety, and efficiency.

1.5 Related Work

There are many companies nowadays manufacturing and selling a similar type of this aircraft with different designs. in Figure 1.1we can see a list of companies that are working in the same field, some of them is using gasoline engines and some other is using electrical power. The designs differ a lot but the thing that is matter is the flight time and the ability to carry multiple types of sensors or payloads which is the competition is about.

	Endurance (h)	Weight (kg)	Payload (kg)	Propulsion	VTOL ?	Analytics	Pricing (€)
VENTURI	6-8	20	3	Hydrogen	Yes	On-board	>75.000
	1-2	15	2	Electric	Yes	On-board	40.000
quantum systems	1	14	2,5	Electric	Yes	No	60.000 (Q2 2017)
ALTi	6	15	1	Gasoline	Yes	No	100.000-120.000 (Q1 2017)
LATITUDE	15	47,5	5	Gasoline	Yes	Tracking	500.000
	2	2	0,2	Electric	No	Cloud	20.000-25.000
delair-tech	2,5	15	4	Electric	No	Cloud	>100.000
UAV FACTORY	20	21,5	4	Gasoline	No	Tracking	>50.000
	2	21,5	2,5	Electric	No	Tracking	>30.000

Figure 1.1: List of companies having a smellier product
Sorce: Venturi Unmanned Technologies

1.6 Limitations

As this type of aircraft is a fixed-wing, there are some limitations of using this type of aircraft because it needs open and wide areas as it has a long wingspan. It's not able to perform in cities as there are too many obstacles and narrow paths, such as buildings and the small areas between the buildings.

1.7 market review

During the last years, the drone market (also known as UAV, Unmanned Aerial Vehicles) has grown exponentially. Drones are replacing previous aerial inspection methods, such as light aircraft, helicopters or satellites. Its main advantages consist of reduced investment and operating costs, as well as human risks since there are no pilots or on-ground operators. PwC estimates the value of business processes replaceable by drone solutions as 127,3 billion dollars. During 2014, 29 VC deals were closed, worth 108 mullion dollars. In 2015, these values increased to 74 deals worth 450 mullion dollars. Among these companies, there are several activities, including image processing software, frame manufacturing or electronic components. Global commercial drone market is expected to reach 5,59 billion by 2020, growing at a 32,22 percent CAGR. So far, the military market has a higher market value, but the tendency is to be overpassed by commercial ones. Gartner consultancy group has recently published his market study, showing a positive outlook.

Sector	2016	2017
Hobby	1,705,845	2,362,228
Commercial	2,799,272	3,687,128
Revenues	**4,505,117**	**6,049,356**
Growth	35.5%	34.3%

Figure 1.2: Drone market
Source : Venturi Unmanned Technologies

Despite being used in fewer cases than a malty-rotor (around 6-8 percent flights), fixed-wing drones are usually more expensive because of their added performance, so their market share is slightly higher. Malty-rotor market share is estimated to be around 77 percent. As a result, the commercial fixed-wing market in 2017 would be worth around 848mn. As an example, Delair Tech, a French startup founded in 2011 in Toulouse by four aerospace engineers had 7,1 million dollars revenues in 2016. The company has a 50 million euros valuation and has been invested in two funding rounds with 4 and 13 million. Based on the posted information, we estimate Delair is selling around 200 DT18 units (low range) and 30 DT26 (high range) per year. Therefore, this success case despite launching their company when there was not a consistent legal framework that allowed to penetrate their potential market.

Chapter 2. Project description and theory

ach aircraft or drone is a full product consist of hardware and software working to gather in harmony. In this chapter will discuss the electrical power system of the aircraft, its components and the related systems. Furthermore, each element will be explained individually. To get the highest efficiency, extra care should be taken for choosing the parts, their ability to work to gather and their suitability for the aircraft system. The complete aerial system for this Project can be divided into five main categories(airframe, autopilot, ground control station, power system, payload). The aircraft has VTOL capabilities and its consists of 5 Motors, one motor for cruising and four motors for vertical take-off and landing. The power system is consists of (batteries, Electronic speed controllers, motors and propellers). Two models will be launched based on the power source selected, electric battery and hydrogen system. Below are the characteristics of the platform shown in Figure 2.1.

- Extended flight time: Up to 2 hours flight time using electric batteries and 8 hours thanks to the hydrogen power system.
- Added functionality. No need for runway. Operate everywhere thanks to the Vertical Take-Off and Landing system.
- Analytics: Up to 3kg of cameras and sensors.
- Autonomous navigation systems: Automatic flight to cut down costs.
- Carbon fibre structure: Lightweight and extra performance.

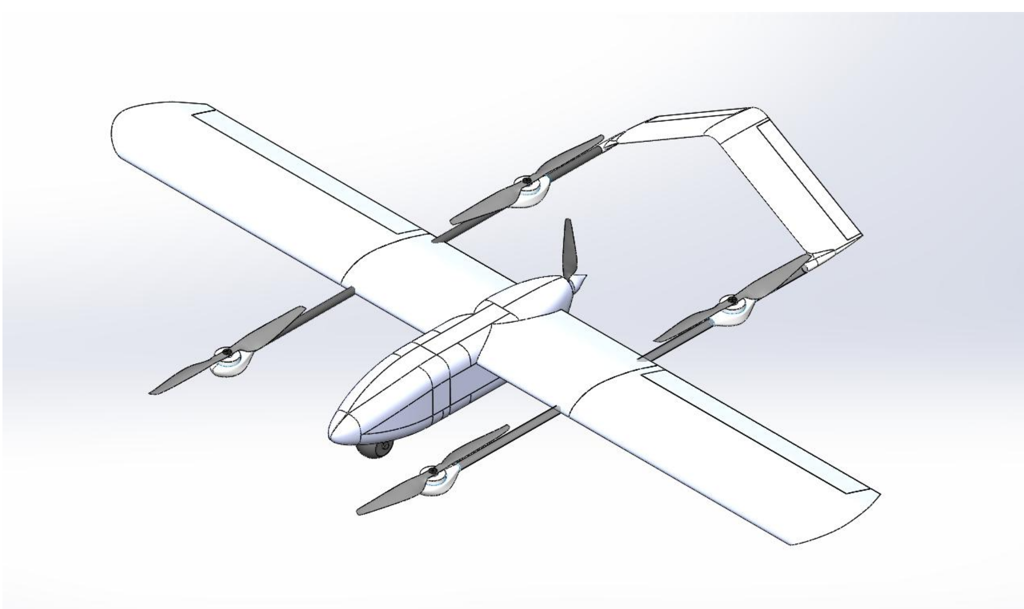


Figure 2.1: The prototype

2.1 air frame

The airframe resembles the aircraft's body which is consist of the fuselage, wings and the tail. The aerodynamics of the frame is a key feature to achieve the optimum performance. An airfoil is the cross section of a wing or a propeller blade even an aileron, in general airfoil is an aerodynamic shape that generates lift perpendicular to its direction of motion. The basic principle behind aerofoils is described by Bernoulli theorem which states that an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or decrease in the fluids potential energy[5]. This is states basically that the total pressure is equal to static pressure plus dynamic pressure. Air that travels over the top surface of the aerofoil has to travel faster and thus gains dynamic pressure. The subsequent loss of static pressure creates a pressure difference between the upper and lower surfaces that is called lift opposes the weight of an aircraft. As the angle of attack (the angle between the chord line and relative air flow) is increased, more lift is created. Once the critical angle of attack is reached(generally around 14 degrees) the aerofoil will stall.

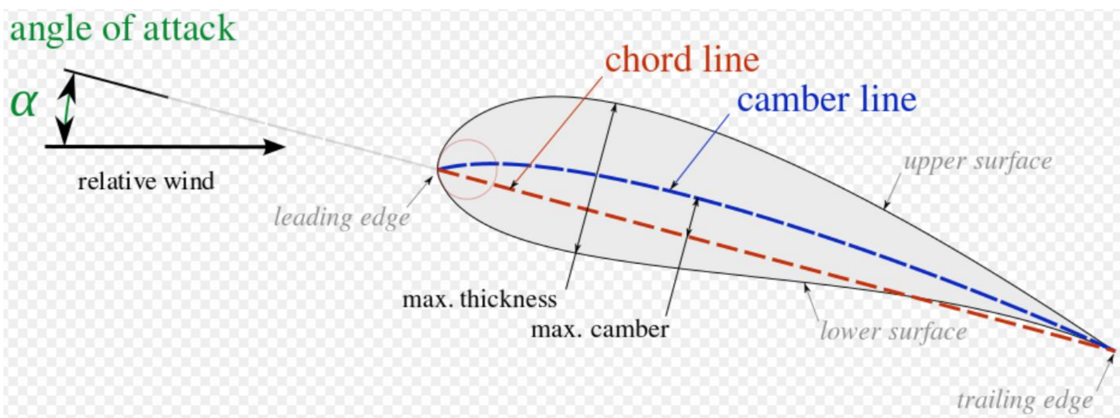


Figure 2.2: aerofoil

2.1.1 Autopilot

The autopilot is a platform used to control the stability and trajectory of an aerial vehicle. The autopilot focuses on assisting or tracking full control of a vehicle in real time. Autopilots have evolved significantly over time. Early autopilots merely held the attitude control compared to modern autopilots capable of performing fully automated missions. There is exists a variety of different autopilots in the market, most of them are custom made and tailored to certain aeroplanes. For smaller planes or fixed-wing drones, the list of available autopilots is also reduced for open-source autopilots that allow modifications to the software. At the beginning of the project, the implemented autopilot was the Pix-hawk 2 board with PX4 stack software. This board is popular amongst hobby applications and is a rather new platform compared to its competitors. For the current aircraft, The autopilot used is MP2x28 from a company called Micro Pilot. MicroPilot is the world-leading manufacturer of professional autopilot for unmanned aerial vehicles(UAV) and micro aerial vehicles (MAV)[6]. Micropilot flies a wide variety of air crafts (helicopters, small fixed-wing, jets, etc.). The MP2x28 autopilot is the worlds smallest full-featured of UAV autopilots. Its Capabilities includes airspeed hold, altitude hold, turn coordination, GPS navigation, Vertical takeoff and landing (VTOL) and autonomous operation from lunch to recovery. Below are the features of this autopilot :

- 150 mips RISC processor gives scalability
- world's smallest UAV autopilot; 28 grams, 4cm by 10cm
- upward compatible with MP2028g2
- GPS way point navigation with altitude and airspeed hold
- completely independent takeoff, bungee launch, hand launch and landing
- powerful command set
- extensive data logging and telemetry collects the data you need
- fully integrated with 3-axis gyros/ accelerometers, GPS, pressure altimeter, pressure airspeed sensors, all on a single circuit board
- UAV configuration wizard and installation video simplifies setup and speeds time to market
- includes HORIZONmp ground control software

2.2 Ground Control Station

To perform Automated flight or a mission, the Ground control station is the software part that communicates with the autopilot and gives the orders to perform tasks autonomously or manually by assigning ground control points on the map provided by the control station to the aircraft to follow. Primarily QGrond Control Station is the software used in this project, QGround Control Station offers full flight control, and vehicle setup for PX4 or any ArduPilot powered Drones or air crafts. It provides easy and straightforward, delivering high-end feature support for experienced users. For the last designed aircraft, Horizon ground control station will be used as it is supplied with autopilot. HORIZON ground control software offers a user-friendly point-and-click interface[7]. Developed by Micro-pilot specifically for the MP2x28 series of autopilot, HORIZON allows an operator to monitor the autopilot, Chang the waypoints, upload new flight plans, initiate holding patterns and adjust feedback loop gains all while the UAV is flying.

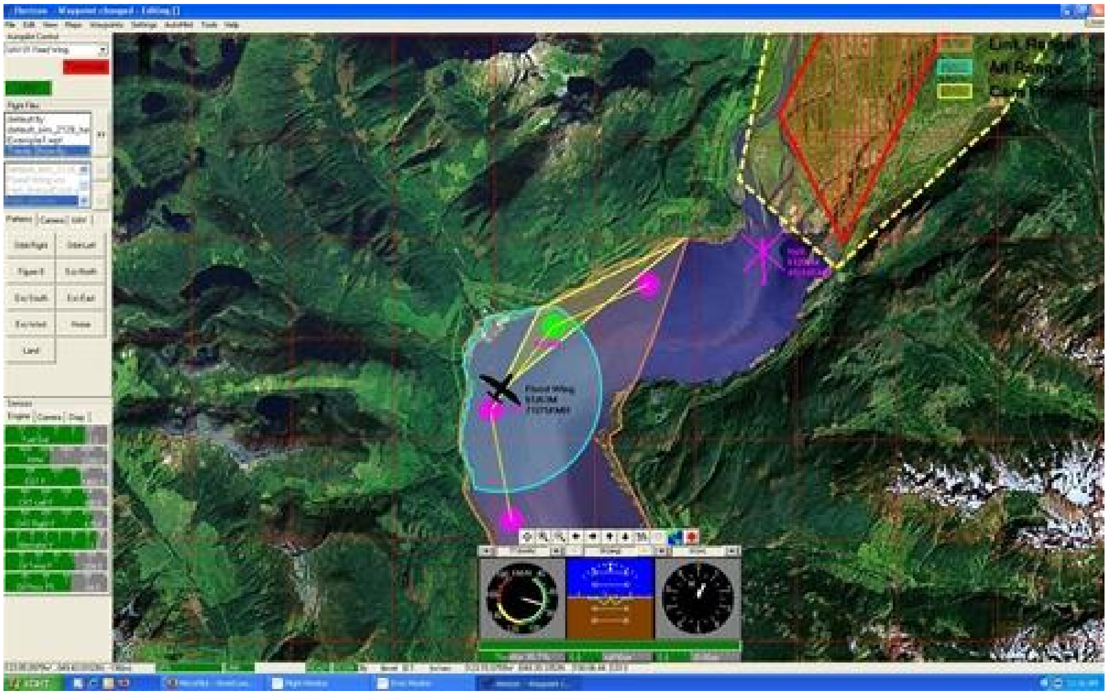


Figure 2.3: HORIZON Ground Control Station

Some of HORIZON ground control station features:

- User configurable payload buttons and sliders initiate holding patterns and control servos
- Features can be enabled or disabled according to the application and user requirements.
- In flight mission reprogramming.
- In flight gain adjustment.
- Communication options support a wide range of radio modems.
- Target altitude and speed can be changed during flight.

2.3 Power system

The power system is the responsible for supplying power to all the components of an aircraft including the motors and all electronics. There is many ways to supply power to the aircraft such as combustion engines that works on gasoline , Electrical power which the main power supplier is batteries, and the last but not the least is hydrogen power system. In this project Electrical power will be used.

2.3.1 Hydrogen power

Hydrogen is a high in power substance , engines that burns pure hydrogen produces almost no pollution. A fuel cell combines hydrogen and oxygen to produce electricity, heat, and water. Fuel cells are often compared to batteries. Both convert the energy produced by a chemical reaction into usable electric power[8]. However, the fuel cell will produce electricity as long as fuel (hydrogen) is supplied, never losing its charge.Fuel cells are a promising technology for use as a source of heat and electricity for buildings, and as an electrical power source for electric motors propelling vehicles. Fuel cells operate best on pure hydrogen. But fuels like natural gas, methanol, or even gasoline can be reformed to produce the hydrogen required for fuel cells. Some fuel cells even can be fuelled directly with methanol, without using a reformer. In the future, hydrogen could also join electricity as an important energy carrier. An energy carrier moves and delivers energy in a usable form to consumers. Renewable energy sources, like the sun and wind, can't produce energy all the time. But they could, for example, produce electric energy and hydrogen, which can be stored until it's needed. Hydrogen can also be transported (like electricity) to locations where it is needed.

2.3.2 Electrical power

In this project Electrical power will be used to drive the aircraft. the process of choosing the right combination of the previous parts is critical to be able to lift all the weight efficiently with minimum power consumption.Figure 1 describes the initial procedure and initial consideration were taken in account at the earliest days of the project. Figure 2.4

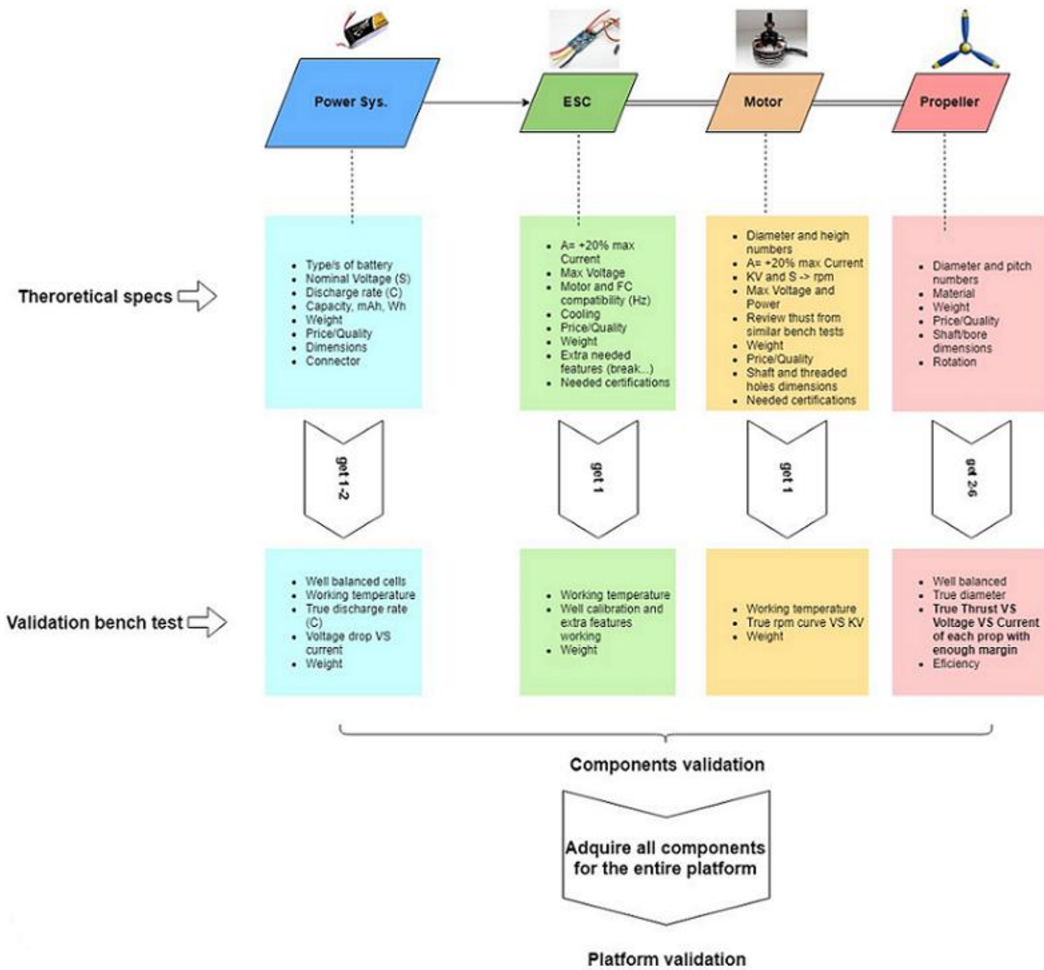


Figure 2.4: selection criteria

2.3.3 Batteries theory

A battery is a device converts chemical energy to electrical energy by a chemical reactions. There is rechargeable batteries and non-rechargeable batteries it depends on the type of the battery[9]. An electric current is created due to the movement of the electrons. As the wind the electrons flow from the high pressure to low pressure (the potential difference known as voltage), this is exactly what the buttery does , it creates a voltage difference by introducing two chemical reactions called " Redox reactions". one of the reactions creates electrons and the other reaction needs them. The batteries consist of tow different state materials one is a liquid solution (electrolyte) and the other is a solid conductor (electrode). By connecting the supply and the demand side electrodes with a conducting wire the electrons is allowed to move from on side to other creating the current and here is the power is generated . There is many different types of batteries exist , they are consisted of different types of materials used as the electrodes and electrolytes.

Batteries is the main power supplier to the hall aircraft components , so the selection of the batteries should consider the amount of power will be consumed by the motors mainly and the other electronics. Lithium-Ion batteries were used in this project because of their high Energy density, light wight to its size, the high discharge rate and the low cost.As the Lion batteries may be bigger in size and Little more weight than the lithium-polymer battery but in the same hand they give more flight time which is the main goal of this project and the wight and size does not consider as an issue because the aeroplane design could handle that. Below a comparison between a Lithium-Ion battery and a Lithium Polymer battery.

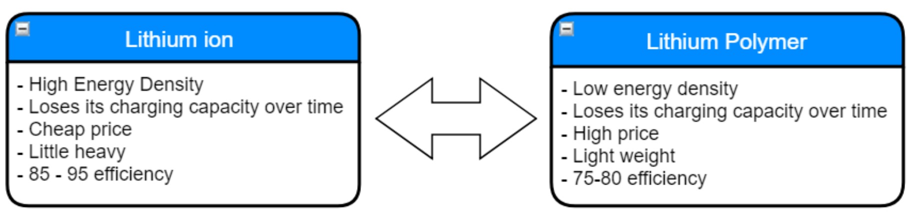


Figure 2.5: Comparison between Lipo and Lion batteries

2.3.4 ESC'S theory

ESC ,The Electronic Speed Controller is an electronic circuit that regulates and control the speed of an electric motor and some of it provides dynamic breaking and reversing of the motor[10]. It has three wires that connect to the motor from one side, it has tow wires from the other side to connect to the battery and a signal wire connects to the receiver.An ESC follows a speed reference signal transmitted buy the throttle liver of the transmitter ,which adjust the duty cycle or it switch the frequency of the transistors so the motor speed will change. Brush-less ESC systems creates three-phase Ac power to run the bruch-less motor. ESC's ratings normally according to maximum current that it could handle. The main category of choosing an ESC's is its compatibility with the motor.The ESC specifications should be higher than the motor specification for example if the motor maximum current is 60 amps the ESC should take at least 80-90 amps so it will be working in a safe range in case the motor draw more current the ESC can handle it easily without worming up or burn , BEC "Battery Eliminator Circuit " its a voltage regulator built into the ESC which can provide regulated 5V DC power to any electronics which need it but not all ESC has it built in , in this case you will need external BEC. Also the ESC should be compatible with the battery used.

2.3.5 Motors theory

There is tow main types of motors brushed and brush-less motors , brush-less motors also has tow kinds out runner and in-runner[11].The main function of the motor in an air plane is to rotate the propeller and create thrust. The main feature to take care of when selecting a motor is the KV which means(rotation per volt) , depending on the size, weight of your aircraft and the type of mission that the aircraft will perform ,a high KV or a Low KV Motor will be chosen. For example , if the aircraft required to be fast and its small in size a high KV motor should be used with a small propeller with high pitch.The weight to power ratio is considered an important detail when choosing a motor , a smaller ratio is abetter motor. Electric motors offer a compact, power

dense, reliable power plant making them ideal for use in UAVs. In particular, brushed and brush less DC motors are well suited to this application. Among these, the brush less DC motor stands out on account of its high power density, efficiency, and reliability. The availability of small, inexpensive power electronics have made brush-less dc motors more cost-competitive and increasingly popular for UAV applications. This type of motors typically have permanent magnets integrated to the rotor while the wingdings held in the stator. They function similarly to synchronous motors, that is by sequentially energising the stator wingdings causing the rotor to turn due to alignment torque. Brush-less motor uses an Electronic Speed Control (ESC) circuit, to perform the commutation. In addition to the stator, rotor, and ESC, brush-less dc motors can include position sensors such as optical encoders or Hall effect sensors to monitor the position of the rotor and perform the commutation more effectively. These sensors can significantly impact motor efficiency, reliability, and performance, and as a result, several, typically larger, brush-less motors use such sensors. The family of brush-less dc motors subdivides into two distinctive categories: axial flux and radial flux motors. are more common, being studied and used in a larger number of applications.There are two motor subcategories: in-runner and out-runner . The former has the stator surrounding the rotor while in the latter, the rotor surrounds the stator. The advantage of out-runner motors is that they have lower speeds and higher torque making them useful for direct-drive applications. Here, the rotor shaft is directly fixed to a propeller without any gearing thereby reducing the weight and complexity of the vehicle, eliminating transmission losses, and reducing costs. The design of a drone or UAV entails proper selection of a motor and propeller combination. In order to perform this selection, it is important to quantify the speed-voltage and torque-current characteristics of the motor as well as the speed-torque-thrust characteristics of propellers. Since motors and propellers have narrow bands of high efficiency operating conditions, a proper selection identifies a propeller which will produce enough thrust to maintain a steady flying altitude while turning at a speed which is optimal for the motor-propeller combination's performance.

2.3.6 Propellers theory

Propellers , and as referred to as "props" are sometimes called screws[12],as a propeller is a device that moves forward through fluids when it turns. Its the rotating part that generate thrust to push or lift the aircraft. Many types and shapes of propeller out there in the market , There are three main shapes of the propellers :

- Pointy nose
- bull nose
- hybrid bull nose

hybrid bull nose is the most efficient and mostly used. Different parts of the propeller moves in different speeds as the blades tips moves faster than than the parts near the hub. A wide range of materials is used to manufacture the propellers such as wood , plastic and carbon fibre. The size and the Pitch of a propeller is varied , selecting the right size and pitch combination is dependant on the weight of the aircraft and type of the mission it will perform.. If more speed is required a high pitch with smaller size propeller will be convenient, If low speed and moor steady flight required a bigger diameter with small pitch will be convenient.In Figure 2.6 we can see the definition of propeller.

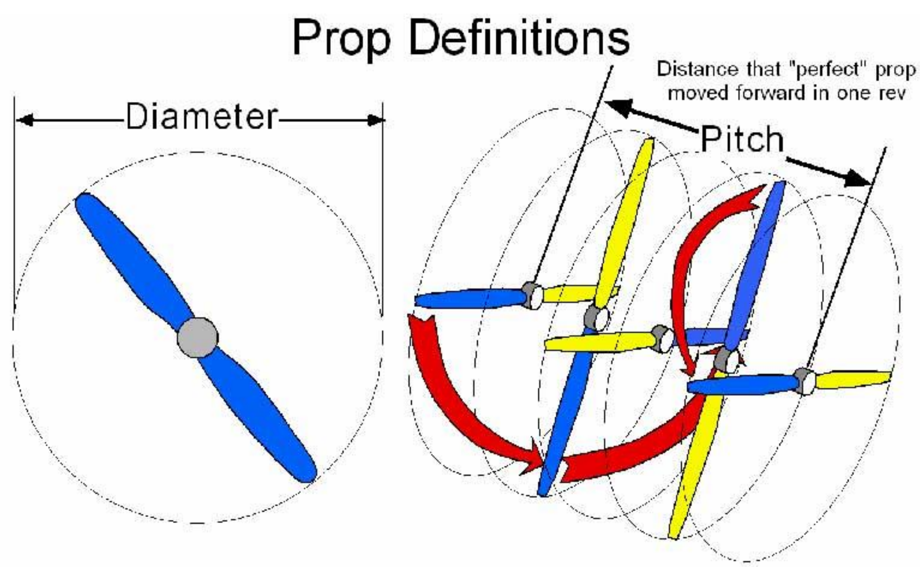


Figure 2.6: Propeller Definition

2.4 Payload

The payload is a weight can be carried by the drone , usually its not counted in the weight of the drone itself but its counted externally as an additional weight such as sensors, cameras, or any other types of packages. The greater of payload The Drone could carry , the larger amount of popping on technology specific to your needs, as upgrading the camera to dual thermal and RBG imaging system an adding a LIDAR technology for example , as its heavier in weight. Knowing the weight of the payload is a key point to calculate the flight time , as the flight time is guaranteed to be reduced when carrying extra weight, because of the additional power required to lift. There are too many types of payloads available now in the markets, Selecting the right payload depend on the type of mission that the drone will perform. Below some kinds of Payloads:

- Cameras
- LIDAR
- Infrared and thermal sensors
- Speed and distance sensors
- Chemical sensors

Chapter 3. Technical specification and design

Two different types of motors were chosen to drive the aircraft , four motors for VTOL and one Cruising motor.Various software was used to get primary theoretical readings for the required power with respect to the air speed based on initial selected motors, propellers, ESC's and batteries. A combination between XFLRS software and a MATLAB code used to determine the theoretical required power needed to drive the drone, a comparison between the theoretical data and the actual data collected from testing will be done to obtain the ultimate combination of motors and propellers. The aircraft weights 25 kg including the payload, the aircraft is designed to be able to carry multiple types of sensors and payloads.

3.1 The air frame specifications

To determine the the power needed to drive the aircraft, all wights should be calculated in order to choose the right motors and propeller combination. The estimated overall wight of the aircraft is 24 kg.

Aircraft wight distribution	
Item	weight(g)
Wing	4515
Stabilizer	804
Fuselage	1800
Landing gear	388
VTOL Structure	950
VTOL Propulsion	2864
VTOL Battery	2300
Cruising Propulsion	605
Main Battery	2800
Payload	3500
Electrical connections	210
Paint	500
Covers	300
Flight Controller	190
Component allocation	400
Total wight	24000

Table 3.1: Aircraft weight distribution.

3.2 Motors

Three models will be tested for the cruising motors , as each one has different characteristics. On the other hand , tow models of motor will be tested for the VTOL. Cruising & VTOL , each has different requirements as for cruising , more rotation per volt is required , but for the VTOL more torque is required hence less rotations per volts.

3.2.1 Cruising Motor

For choosing the cruising motor, three different types of motors were tested. All the cruising motors is from Hacker motors brand and the models are A60, Q80 and A50 which has been tested with a various propellers sizes and materials such as wood, carbon fibre and plastic. The specifications of the motors are listed in Figure 3.1 For cruising motor a high KV is preferred because it has higher RPM combined with a high pitch propeller so it don't stall at high speeds.

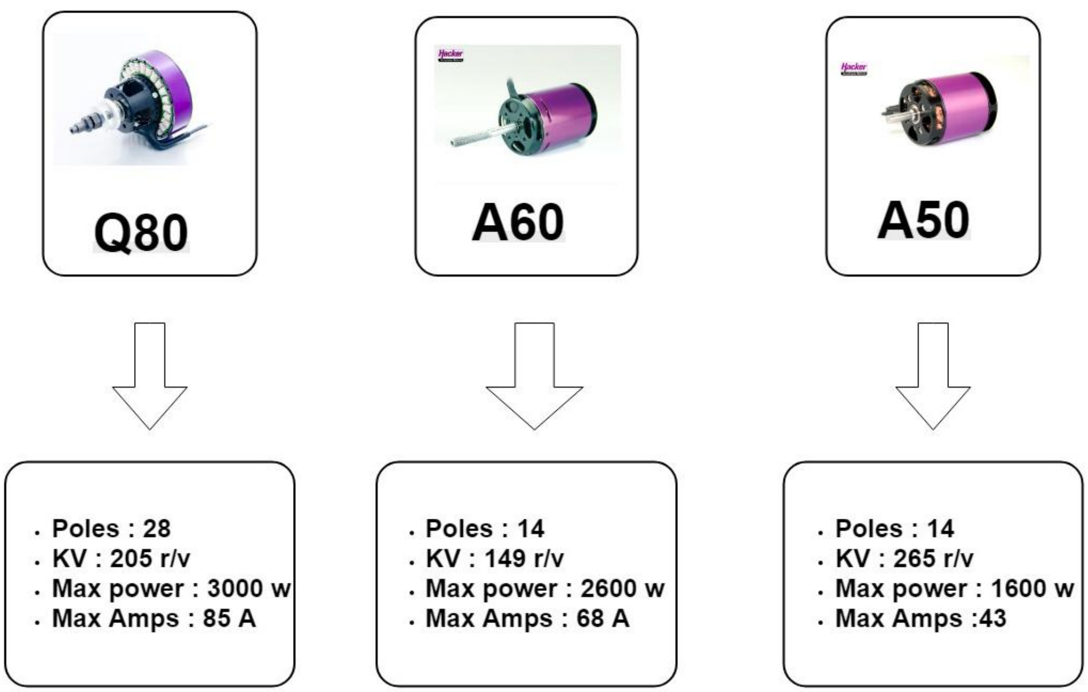


Figure 3.1: cruising motor specifications

3.2.2 VTOL Motors

Tow types of motors will be tested to be used for vertical takeoff and landing , the motors brand is T-Motor which is a leader brand in the market for its quality and durability. As they will be used only for takeoff and landing not in cruising they have to be able to carry all the weight of the drone. Figure 3.2 shows the motors and their specifications. For the VTOL motors a low Kv is preferred for a steady take off and lading a combined with low pitch propeller.

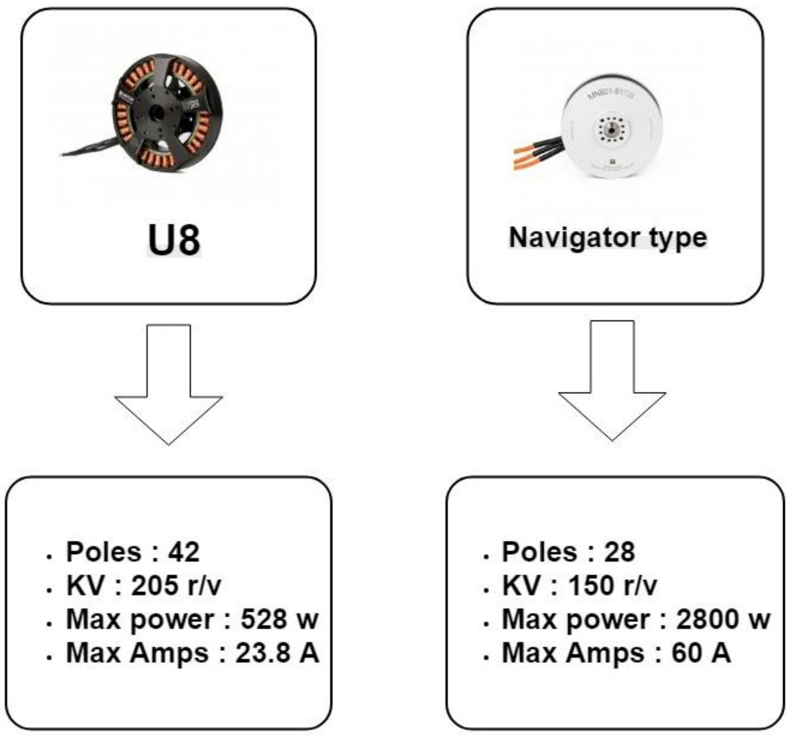


Figure 3.2: VTOL motor specifications

3.3 Propeller Specification

Various sizes of Wooden Propellers were tested with the cruising motors,The wood material was chosen because of the rigidity feature . the sizes 19x15 ,21x14,24x10 and 24x12 were used with the A60 Motor. Propeller sizes 21x14,22x12 and 24x12 were tested with Q80 motor. Propeller sizes 16x10, 18x12, 20x15 used with A50 motor. some of the propellers was recommended by the motor manufacturer and the rest was chosen by us. For the VTOL motor Carbon fibre propeller was used with the size of 26.2x8.5 Figure 3.3.

(a) Cruising propellers (b) VTOL Propellers

Figure 3.3: Propellers

3.4 ESC's Specifications

The used ESC for the cruising motor is Master Spin 99 pro op-to , which can stand 12-50 volts and the max amperes is 90 A. For the VTOL motors the same ESC had been used. Its important the capacity of the ESC to be more than the power drown by the motor , for example if the motor maximum amperes is 60 , the ESC should stand 70 A and more so it don't burn or heat up.

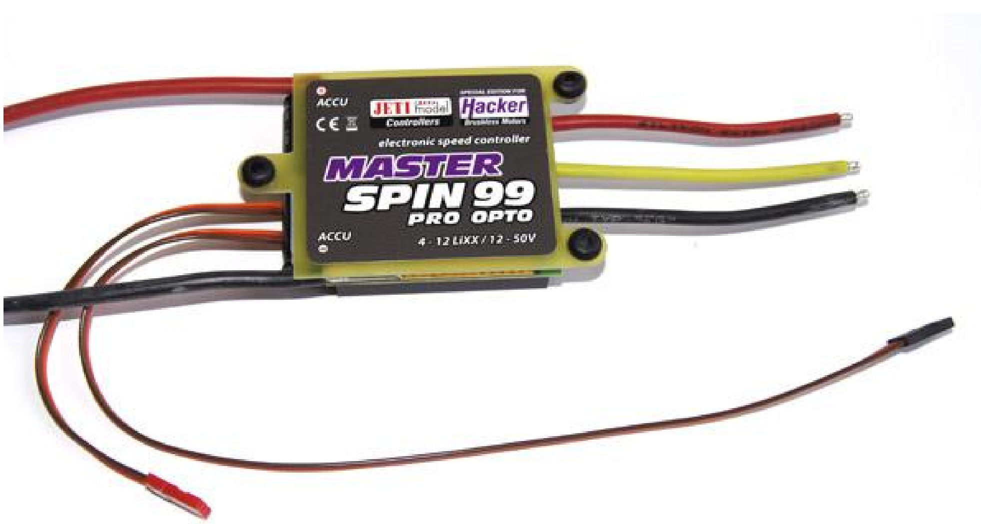


Figure 3.4: Master spin99 ESC

3.5 Batteries Specifications

The batteries that will be used is Lithium Ion batteries,Figure 3.5, the main features of these type of batteries is their high discharge rate and their capacity. The specification of the batteries as shown in the following figure, its a 6S (6 cells) with a capacity of 17500 mAh , 22.2 volts for all the cells which give a 3.7 volts per cell. despite they are a Little heavier than Lithium Ion batteries, they have higher capacity and can give longer flight time as their weight don't affect the fixed wing performance.

Figure 3.5: Battery

3.6 Aircraft control

A radio transmitter will be used to manually control the aircraft. Taranis radio transmitter is used widely for controlling RC air crafts and drones which is mainly used for hobby, its considered from the top transmitters out there in the market. below is the specifications of the transmitter :

- Up to 16 channels
- Dual module two frequency system
- Three selectable modes
- Update the firmware via SD card directly, without the need to install any driver
- Supported smart port, USB, Haptic
- Party receiver, RSSI (receiver signal strength)
- Audio voice output (values, alarms, settings, etc.)
- Flight data recording in real time
- Vibration alerts

Chapter 4. Testing

4.1 Pre-Testing

Before beginning the test some procedures shall be done. Preparing the testing bench and At the beginning of the project, a prototype was built and used to test the software and the hardware in general. To get the most efficient combination, first XFLR software as shown in Figure 4.14 was used to design the aerodynamics and the shape of the aerofoil of the aircraft, furthermore to get the drag coefficient due to lift. Then this coefficient used in a mat-lab code and combined with parasitic drag to get the total drag induced by the aircraft and the power requirements at multiple air-speeds. In theory, the previously calculated drag is equal to the thrust required to fly

the aircraft, a flight was performed using the A50 Motor and the power consumption of the motor was recorded at multiple air-speeds. Now to be able to compare the Drag and power consumption, a Dynamic testing were performed especially to get the thrust readings at the same air-speeds that were calculated theoretically to be able to get a corrective coefficient and us it to correct the power consumption to get new readings and use it for the newly designed aircraft.

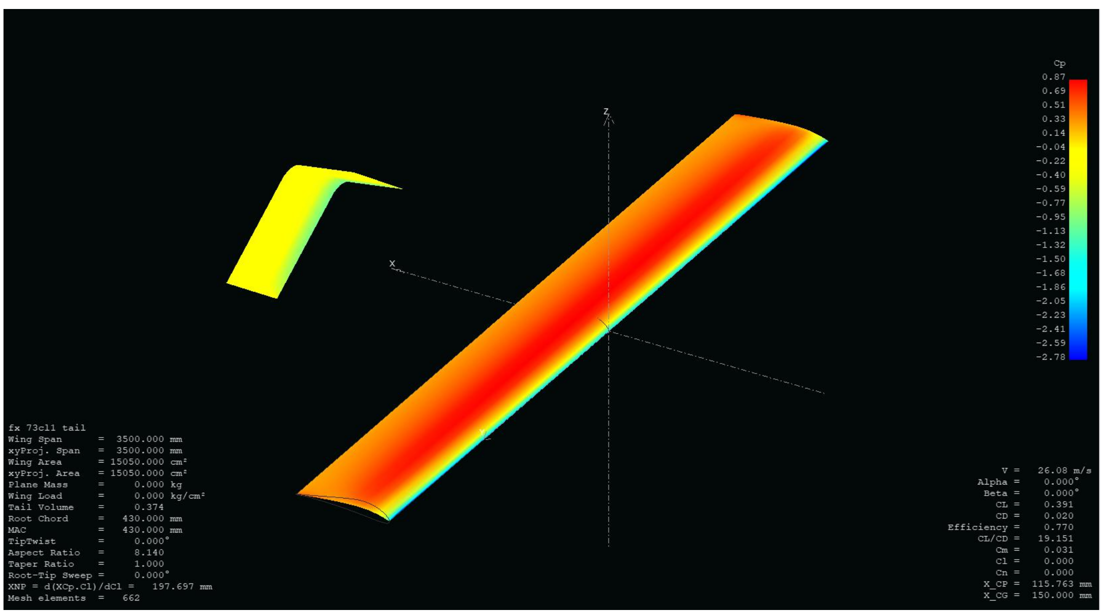


Figure 4.1: XFLR

4.2 The Testing Bench

A thrust bench was used to perform the static test, its a EDF Testing Bench Base V2 from lander technologies . The bench could stand up to 10 kg of thrust which is in the range of required thrust for the Fixed wing Figure 4.2.

(a) the bench (b) thrust meter

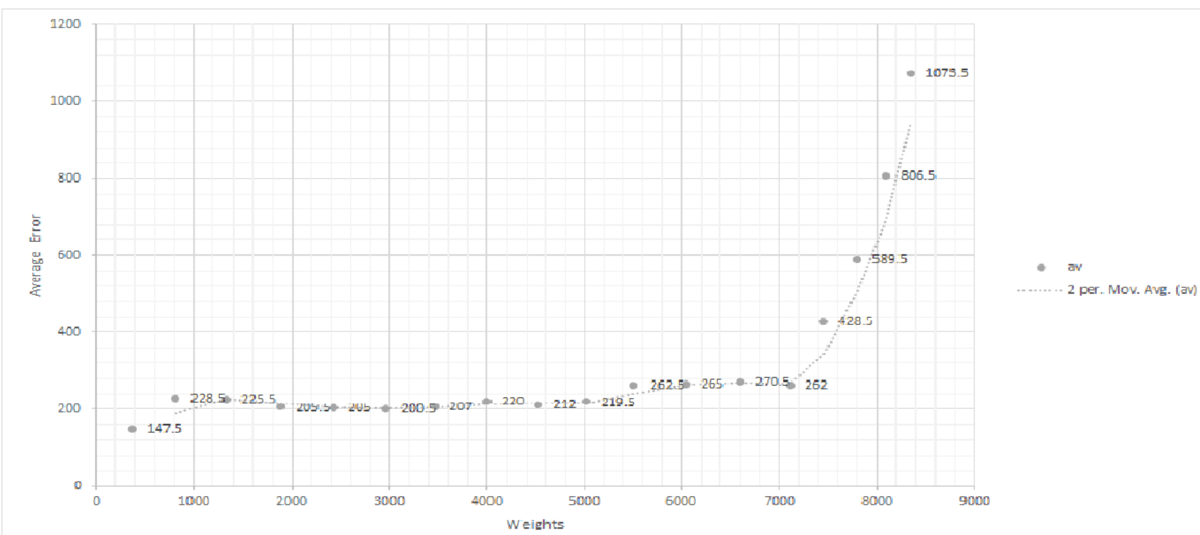
Figure 4.2: Thrust bench

4.3 Testing Bench calibration

All electronic devises has an error range , usually If the device well made this error will be very small most of the times is negligible. However the error was small after a constant use of the device it will need re calibration ,to make sure that it gives an accurate results. For this testing bench that it will be used for testing the motors , a calibration process has been done for it, as it consist of multiple parts the error could could be produced by any part, so a calibration should be done for all the system. First well known weights was weighted on a digital scale to get the most accurate weight, then the weights was applied on the thrust bench which the main sensors is a load cells. The weights was added one by one as each one is 500 g until it reach 10 kg which is the limits of the load cells, then Perform a comparison between the actual weight and the reading showing on the monitor, after that a calculation for the error percentage was performed and a correction factor was calculated to be added to the readings after performing the test, as shown in Figure 4.3.

Firs attempt					Second attempt							
Weight	Scale	Bench	Error		Weight	Scale	Bench	Error		Average Bench readings	Average Error	Avrg of Average error
500	514	372	142		500	513	360	153		366	147.5	223.6428571
1000	1041	828	213		1000	1041	797	244		812.5	228.5	
1500	1547	1361	186		1500	1547	1282	265		1321.5	225.5	
2000	2090	1931	159		2000	2090	1838	252		1884.5	205.5	
2500	2635	2479	156		2500	2636	2382	254		2430.5	205	
3000	3161	3006	155		3000	3159	2913	246		2959.5	200.5	
3500	3675	3509	166		3500	3674	3426	248		3467.5	207	
4000	4217	4048	169		4000	4218	3947	271		3997.5	220	
4500	4733	4557	176		4500	4733	4485	248		4521	212	
5000	5235	5064	171		5000	5234	4966	268		5015	219.5	
5500	5776	5530	246		5500	5776	5497	279		5513.5	262.5	
6000	6313	6100	213		6000	6316	5999	317		6049.5	265	
6500	6863	6526	337		6500	6864	6660	204		6593	270.5	
7000	7377	7065	312		7000	7378	7166	212		7115.5	262	
7500	7882	7488	394		7500	7883	7420	463		7454	428.5	
8000	8389	7840	549		8000	8391	7761	630		7800.5	589.5	
8500	8900	8174	726		8500	8899	8012	887		8093	806.5	
9000	9414	8372	1042		9000	9415	8310	1105		8341	1073.5	

(a) Callibration data

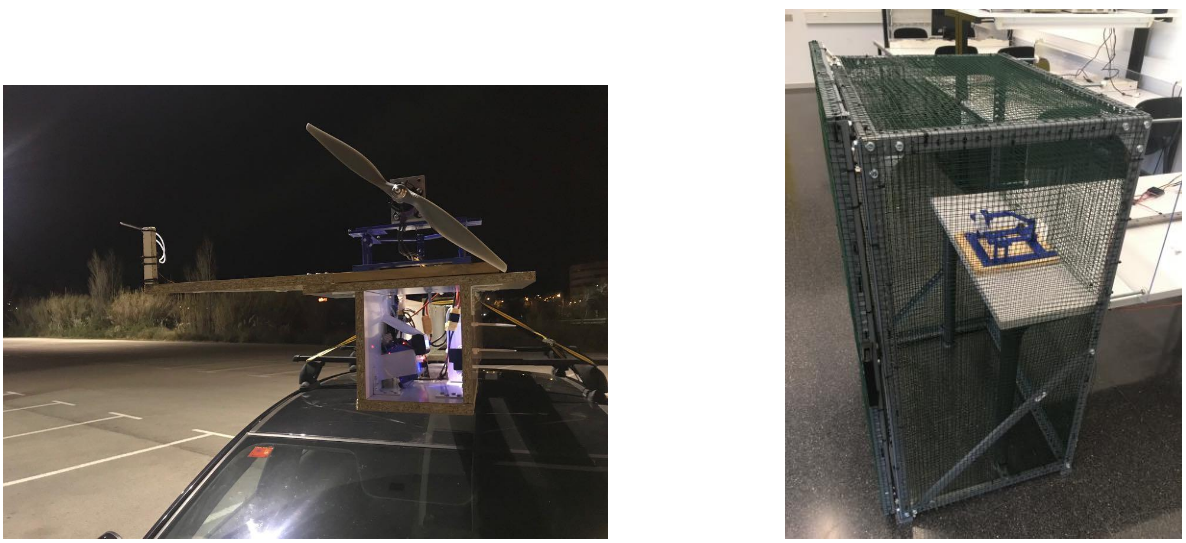


(b) Error curve

Figure 4.3: Calibration

4.4 Testing

To get the ultimate performance, a several static and dynamic tests were performed for motor propeller combinations to see the behaviour of each combination and to get the best combination that gives more thrust with efficient power consumption. A specially designed testing bench was built to mount the motors and do the test. The static tests for the VTOL motors was performed in the lab inside a cage for safety. On the other hand the dynamic test for the cruising motors was performed using a car and a special platform built to mount the motor on it and to be mounted on top of the car to be able to test the performance of the motor/propeller combination at multiple air speeds. In order to perform the experiments consistently, it was necessary to follow procedures for collecting data. Two separate procedures were developed for the static and dynamic tests. For all of the tests, the power supply driving the motor propeller was the same batteries that will be used in the aircraft.Then, the data acquisition was by a camera. For the dynamic test a pitot tube was used to control the air speed. Figure 4.4 shows the tow set ups for testing.



(a) Dynamic test (b) Static test

Figure 4.4: Testing arrangements

4.5 Static test

Static tests usually performed to know the actual thrust that the motor/propeller combination can produce. As there is 4 motors will be used for VTOL, and these motors shall be able to lift all the weight of the aircraft. Static test was done for two Types of motors, U8 T-motor and Navigation Type T-motor. These motors to be used as VTOL motors so the important aspect here is to test it statically because it will not be used for cruising. Dynamic test will not be performed to these motors as it will be stopped while cruising. On the other hand , the cruising motors was tested statically to check their ability to move the aircraft from stopping position.

4.5.1 building the platform

To perform the static test for the motor and propeller combinations , the motor was mounted on the thrust bench, as shown in the following figures using a L-shape metal piece, the metal piece was drilled to fit the motor and the thrust bench Figure 4.5. The Metal piece was tested so it don’t bend or deflect during the test by applying 10 kg of weights to it and see the effect of the weight on it, as the maximum force will be 10 kg which is the maximum of the load cells. This piece was used to mount both the A50 and the U8 motors.

(a) Parts

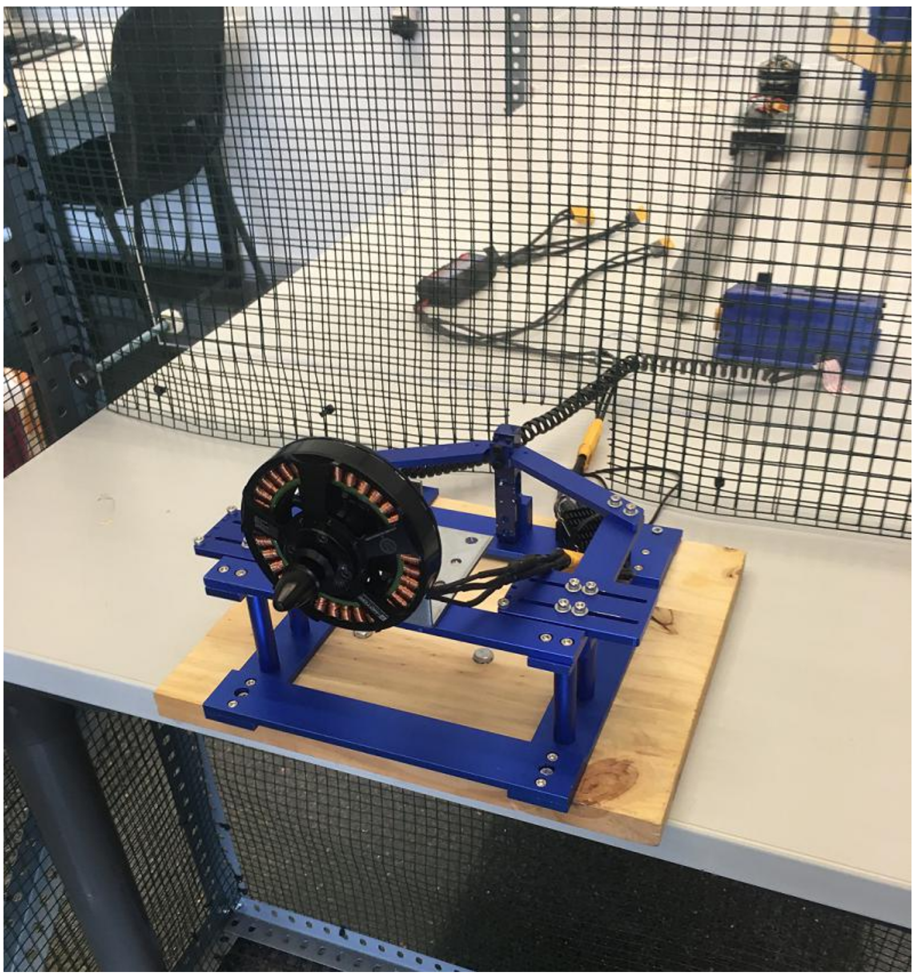
(b) Drilling the L-Shape metal piece

(c) Motor mount

Figure 4.5: Building up

4.6 setting up

First the thrust bench was mounted on a piece of wood , then screwed to the table inside the cage using tow screws. As shown in Figure 4.6 , the motor was mounted on the thrust bench using the L shape metal piece, after wards the ESC was connected to the motor then the ESC was connected to the malty-meter, finally the malty-meter was connected to the battery. The last thing to do is attaching the propeller after assuring that the system is working good. To power up the system, two 6S Lipo Batteries as the initial batteries to be used in the drone. the thrust reading were displayed on the thrust meter, the Amperes, power and the voltage was displayed on the malty-meter. All data were collected using a camera.



(a) Arrangements

Figure 4.6: setting up

4.6.1 performing the test

The test was performed inside a cage for safety.the temperature of the motor and ESC was monitored during the test, safety is very important when performing such kind of test because any failure from the motor or propeller, the consequences will be very dangerous. The first test was for the U8 T-motor with the propellers size (22x6).The motor was testes on 25, 50, 75 and 100 percent of thrust. The methodology of performing the test was as follows:

- Attach first propeller
- attach the batteries
- move the potentiometer to 25 percent
- wait to stabilise
- collect the data
- repeat for 50, 75 and 100 percent

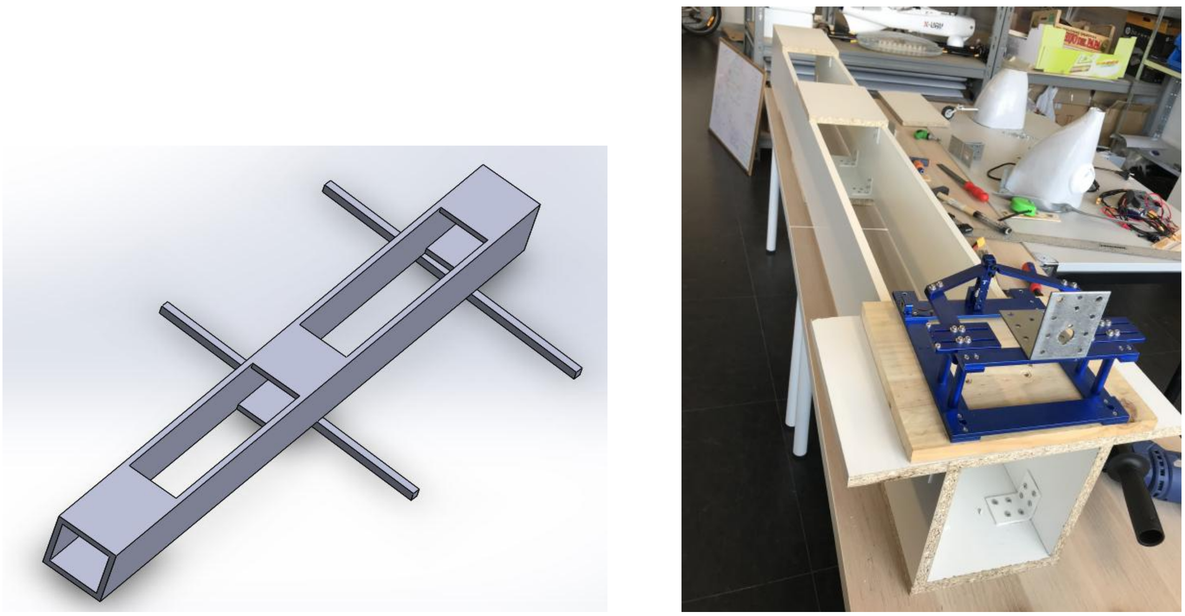
The maximum power of the motors was monitored along the test so it don't get overpowered. The same test was Performed for the Navigation type T-Motor with a propeller size (26x8.5). All The results and data will be discussed in the upcoming sections.

4.7 Dynamic Tests

Three motors were tested dynamically which are A50,A60 and Q80 Hacker motors. As the motor will be used as a cruising motor It should be tested Dynamically. The Motor-Propeller combination is pushing a fixed wing drone, that indicates that the thrust force will differ along different air speeds and wind speed. Dynamic tests were performed specially for the cruising motors to have the ultimate performance of the drone and to check at wich speeds the propeller will stall. Each Motor was mounted on the platform and tested statically, and dynamically at multiple air speeds ranging from 10m/s to 30m/s which is the range that the drone will perform in.

4.7.1 building the platform

A special platform was built out of wood as you can see in figure 3.3 The platform was designed using solid-works and then was built out of wood which was cut according to the design and attached using L-shape metal pieces. The thrust bench was attached on the top front of the platform and all electronics and batteries was attached inside the platform. Pi-tot tube was attached also to measure the air speed. A Pixhawk was used to read The pitot tube and display the reading using Q-ground control station program. Figure 4.7



(a) Platform design (b) The Platform

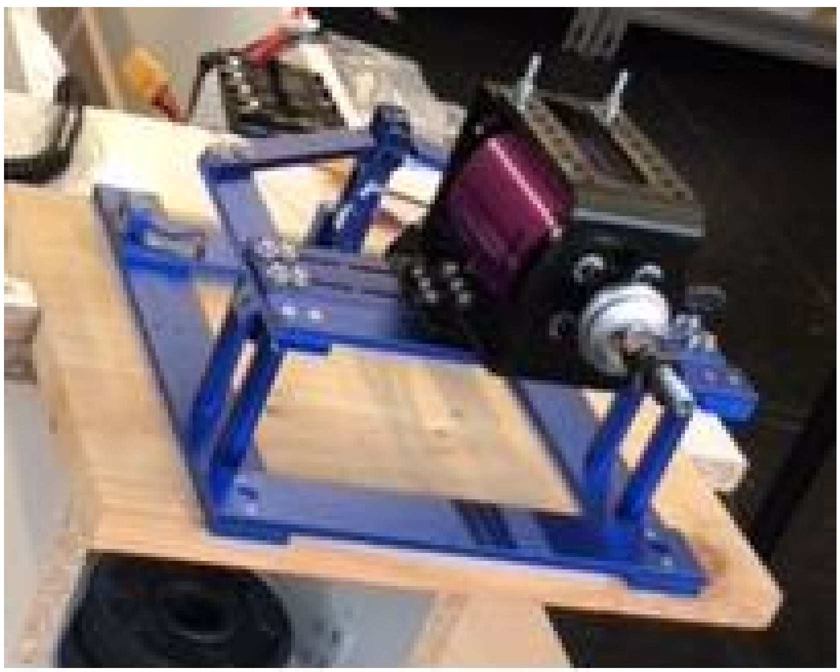
Figure 4.7: The platform

4.7.2 A50 motor mounting

The A50 motor was mounted on the same L-shape metal piece as discussed previously in section 4 , Figure 4.5.

4.7.3 A60 motor mounting

As shown in the figure below the A60 motor was mounted on the platform using a special aluminium mount that holds the motor from front and back. then the motor and the mount were attached to the platform using a piece of carbon fibre.

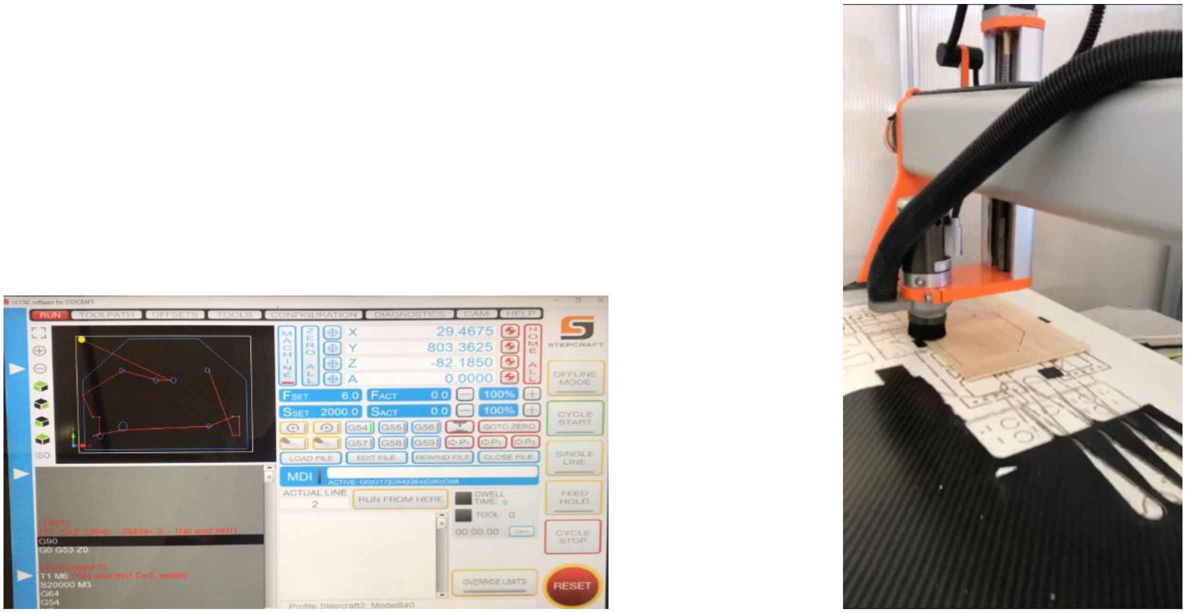


(a) A60 mounting

Figure 4.8: motor mount

4.7.4 Q80 motor mount

CNC machine was used to cut the carbon fibre piece to the exact dimensions. First the piece was designed using solid works , then the file was loaded to the CNC for cutting. Figure 4.9 shows the CNC software and machining



(a) CNC Software (b) CNC machining

Figure 4.9: Q80 mounting

For Mounting the Q80 motor , tow L shaped Pisces of metal where used to mount the motor on them and a especial designed piece of carbon fibre was used to mount the metal Pisces on it. the motor is big and needs a strong structure to keep it in place. the following figures shows the mounting elements.

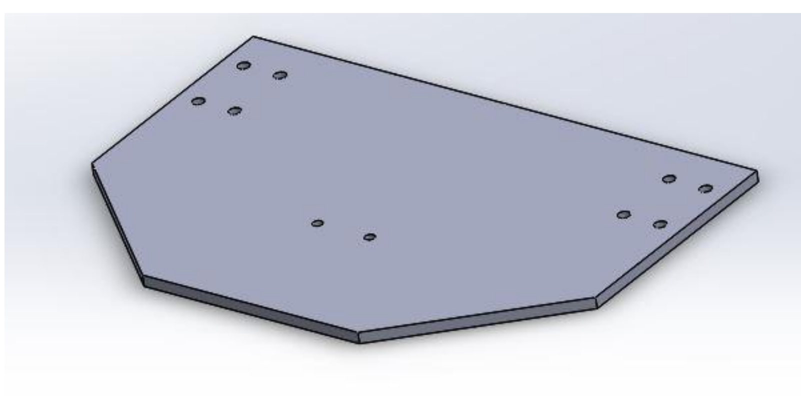


Figure 4.10: Carbon fibre piece

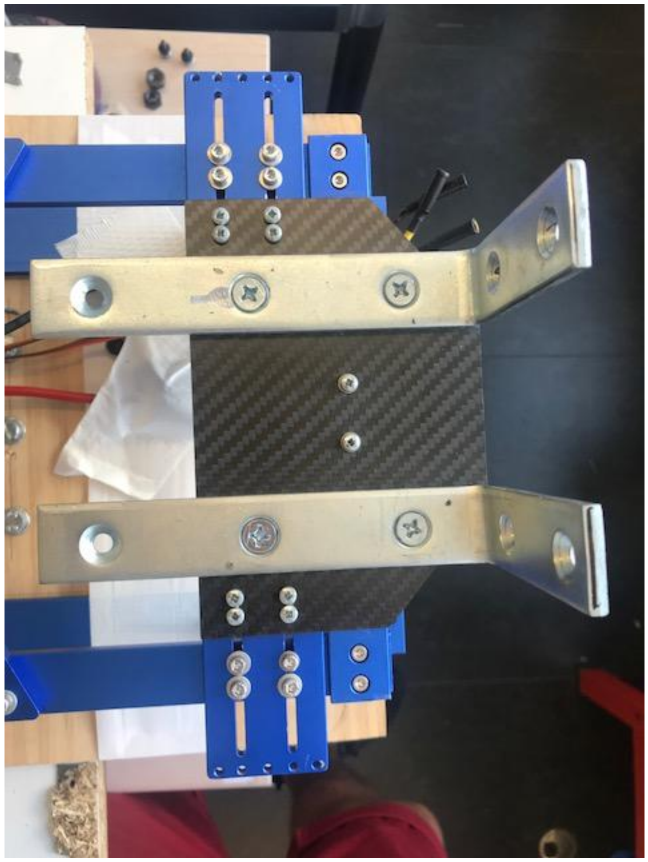
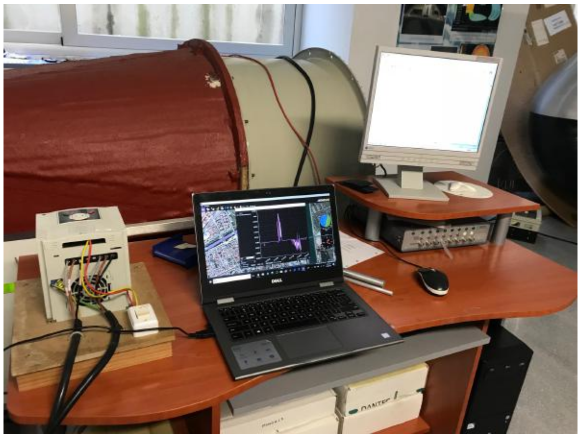


Figure 4.11: Q80 mount

Figure 4.12: Q80 mounted

4.7.5 Pitot tube calibration

To check if the pitot tube is well calibrated , a wind tunnel in the university was used. The wind tunnel has a calibrated and steady wind speed with a built in pitot tube. Our pitot tube was placed inside the wind tunnel , then we are able to compare the readings and make sure our pitot tube is functioning well as you can see in Figure 4.13



(a) Wind tunnel

(b) reference pitot tube

Figure 4.13: Pitot-tube calibration

4.7.6 Performing the test

The same procedure were performed For both of motor The motor was controlled from inside the car using a transmitter-receiver system where the receiver is connected to the ESC. The camera was connected via WIFI to a cellphone and the phone was connected to the laptop to show the readings of the thrust and multimeter on the laptop screen, the pixhawk also was connected to the laptop to show air speed. The test procedure was as follows :

- Attach first propeller.
- attach the batteries.

- connect the pixhawk to the laptop.
- display the camera streaming on the laptop screen along with the air speed which is displayed by Q Ground Control station.
- start recording the screen.
- Go to the first air speed.
- move the transmitter stick to 25 percent of throttle.
- wait to stabilise.
- repeat for 50, 75 and 100 percent.
- move to the second air speed.
- repeat for 25,50, 75 and 100 percent of throttle.

4.8 Drag test

As The VTOL motors will be stopped while the aircraft will be in cruising mode , the motor and propellers will produce drag force. The orientation of the propellers make a lot of difference in drag wise, as if the blades of the propeller was stopped perpendicular to the airflow it will produce high amount of drag , in the other hand if the propellers was topped parallel to the airflow it will produce less drag. In order to know the amount of drag that the motor/propeller combination will produce , a drag test was performed using the dynamic test platform (section 4.4). The first attempt was by holding the propeller perpendicular to the airflow and measuring the drag (which is equal to the thrust) at different air speeds (10,15,20,25 and 30). The second attempt was by holding the propeller parallel to the airflow and do the same. The results of this drag test will be used to calculate the total drag of the aircraft.

Air speed m/s	T Motor Drag (g) Propeller perpendicular to air flow	Drag (N)	T Motor Drag (g) propeller parallel to air flow	Drag (N)
0	0	0	0	0
10	65	0.63765	40	0.3924
15	150	1.4715	110	1.0791
20	230	2.2563	130	1.2753
25	330	3.2373	250	2.4525
30	510	5.0031	356	3.49236

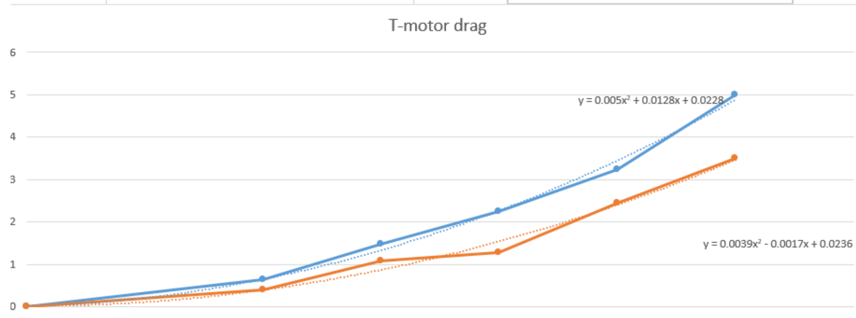


Figure 4.14: T Motor drag test

Chapter 5. Results

The results gathered from the videos are implemented on an excel sheet along with the theoretical results calculated using mat-lab to be able to generate curves and check the corresponding intersection area between the curves which is the desired area so we know the amount of power we have and the amount of power we need , then we will be able to decide if the system is efficient enough or not. On the x axis we have the air speed and on the y axis we have the power, the Gray curve is the minimum required climbing power , and the red curve represent the drone minimum required power (drag) for horizontal cruising. These two curves (Gray and red) is obtained using a Mat-lab Code combined with drag calculations using X5 software. The green curve represent the experimental Power we have using the data collected from the testings. The area between these curves represent the manipulating range that the drone could fly efficiently.

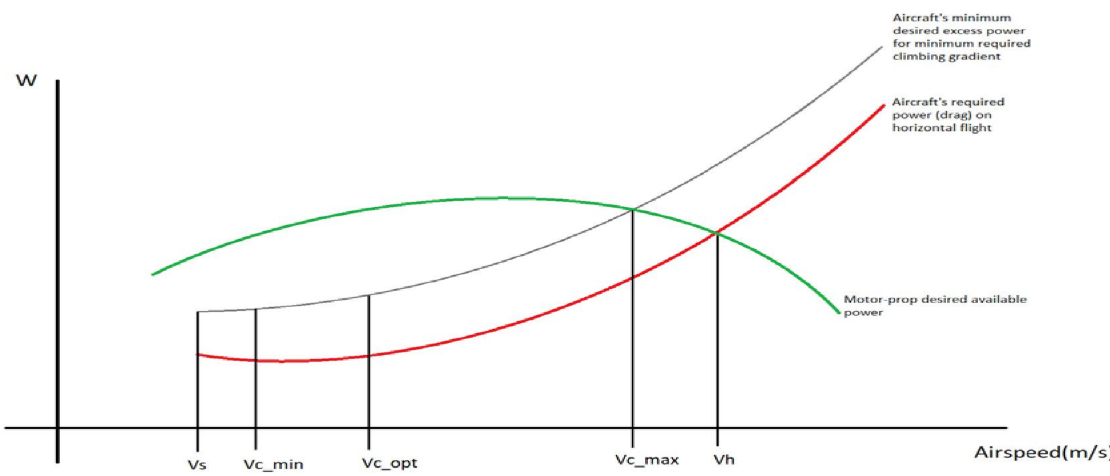


Figure 5.1: Power curves

5.1 Desired Power curve

The following figures shows the theoretical minimum required power and the minimum required climbing power that the drone needs to be able to perform an efficient flight.

Air density is 1.225 kg/m^3, air temperature 15ºC and kinematic viscosity 1.5e-5m^2/s

			20.3
Airspeed (m/s)	**Required Power (W)**	**8.3% climbing minimum power (W)**	
49.862	5566.3	6578.4986	
47.315	4475.4	5435.8945	
44.149	3679.2	4575.4247	
41.229	3034.7	3871.6487	
38.695	2541	3326.5085	
36.533	2165.7	2907.3199	
34.665	1874.1	2577.7995	
33.015	1642.1	2312.3045	
31.584	1458.4	2099.5552	
30.334	1310.6	1926.3802	**Vc_max=maximum cruising speed (not the maximu**
29.221	1188.7	1781.8863	
28.223	1086.8	1659.7269	
27.32	1000.6	1555.196	
26.499	926.96	1464.8897	
25.748	863.61	1386.2944	
25.057	808.67	1317.3271	
24.419	760.67	1256.3757	
23.828	718.95	1202.6584	
23.278	682.03	1154.5734	
22.765	649.16	1111.2895	
22.284	619.77	1072.1352	
21.832	593.4	1036.5896	
21.407	569.65	1004.2121	
21.006	548.21	974.6318	
20.627	528.77	947.4981	
20.268	511.11	922.5504	
19.927	495.02	899.5381	
19.604	480.32	878.2812	**Vc_opt =Optimal cruising speed**
19.295	466.9	858.5885	
19.001	454.55	840.2703	
18.721	443.17	823.2063	
18.453	432.71	807.3059	
18.196	423.06	792.4388	
17.95	414.16	778.545	
17.713	405.93	765.5039	
17.487	398.31	753.2961	
17.269	391.32	741.8807	
17.059	384.85	731.1477	
16.857	378.84	721.0371	
16.662	373.26	711.4986	
16.474	368.05	702.4722	
16.292	363.21	693.9376	
16.117	358.71	685.8851	
15.947	354.52	678.2441	
15.783	350.6	670.9949	
15.624	346.95	664.1172	
15.47	343.53	657.571	
15.321	340.35	651.3663	
15.176	337.37	645.4428	
15.036	334.58	639.8108	
14.899	331.98	634.4297	
14.767	329.55	629.3201	
14.638	327.28	624.4314	
14.513	325.15	619.7639	
14.391	323.17	615.3073	
14.272	321.31	611.0316	
14.156	319.57	606.9368	
14.044	317.95	603.0432	
13.934	316.44	599.3002	
13.827	315.06	595.7481	
13.723	313.77	592.3469	
13.621	312.56	589.0663	
13.522	311.44	585.9366	**Vc_min=Minimum cruising speed**
13.425	310.39	582.9175	
13.33	309.42	580.019	
13.238	308.51	577.2414	
13.147	307.67	574.5541	
13.059	306.89	571.9877	
12.973	306.18	569.5319	
12.888	305.52	567.1464	
12.806	304.91	564.8718	
12.725	304.35	562.6675	
12.646	303.84	560.5538	
12.568	303.37	558.5004	
12.492	302.93	556.5176	
12.418	302.54	554.6254	
12.345	302.19	552.7935	
12.274	301.86	551.0222	
12.204	301.57	549.3112	
12.135	301.31	547.6505	
12.068	301.08	546.0604	
12.002	300.87	544.5106	**Vs=Stall speed**

(a) Theoretical data

Figure 5.2: Theoretical Data

From the previous data now we are able to plot it and have the theoretical performance curves as shown in the figure below. As the Orange curve represent the minimum desired climbing power and the blue curve represent the minimum desired cruising power.

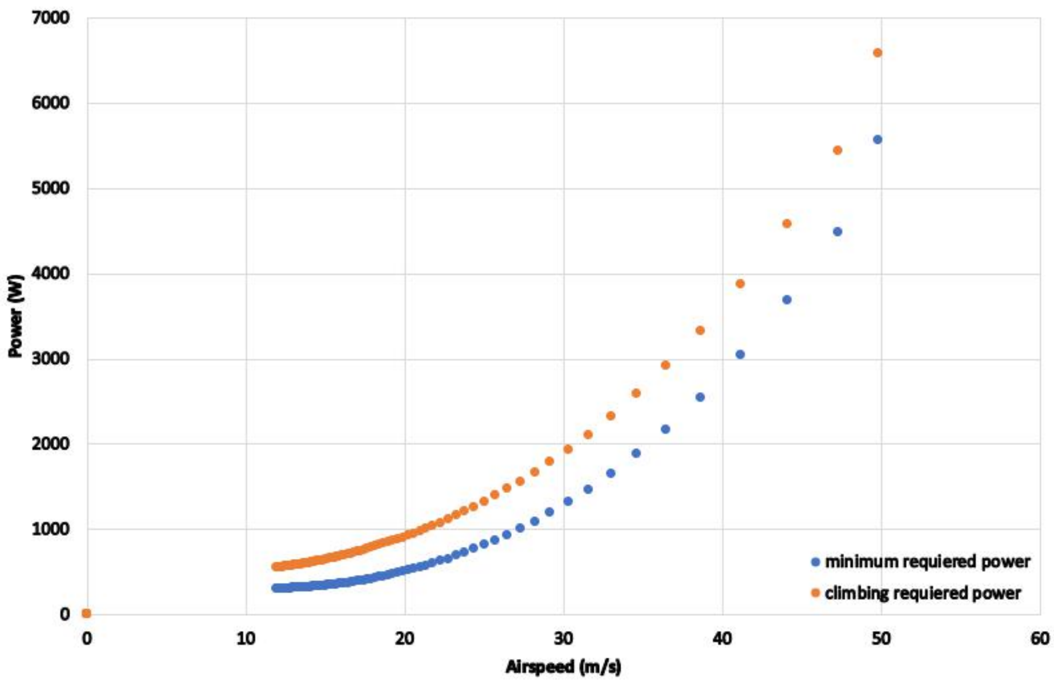


Figure 5.3: Theoretical data curves

5.2 Motors performance

5.2.1 A50 motor performance

Figure 5.4,Figure 5.5 and Figure 5.6 shows the performance of the A50 motor , The motor was tested with Three different propellers sizes and pitch (16x10,18x12 and 20x15).

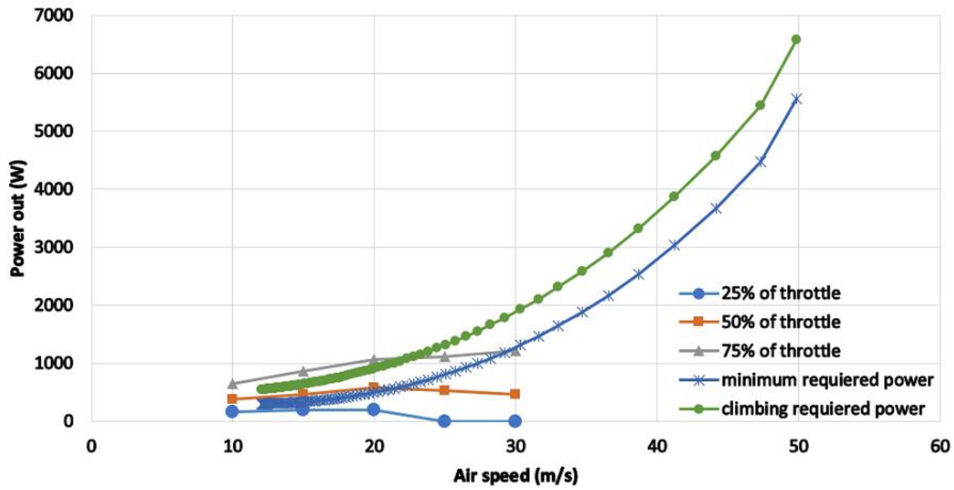


Figure 5.4: A50 with 16x10 propeller performance

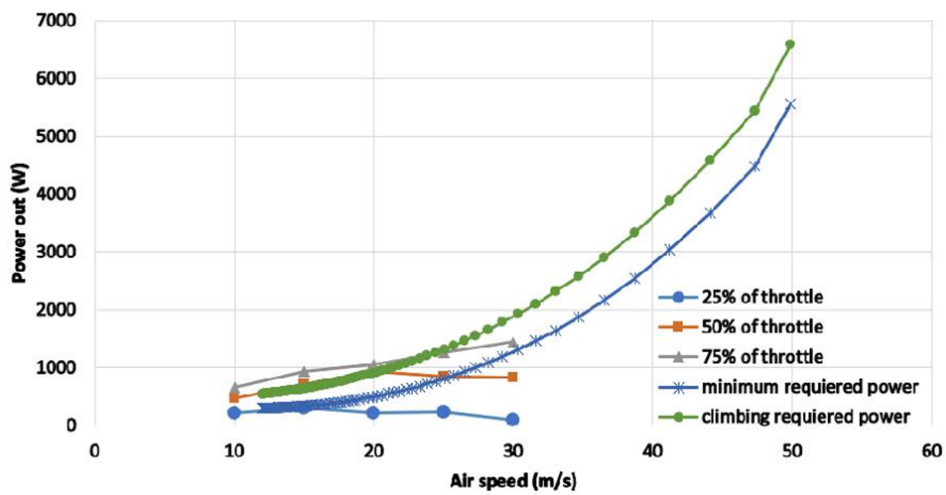


Figure 5.5: A50 with 18x12 propeller performance

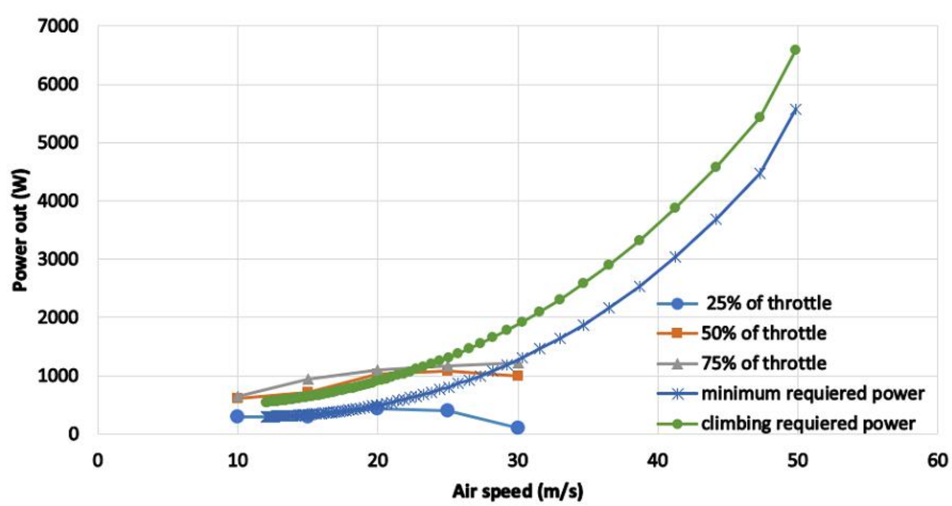


Figure 5.6: A50 with 20x15 propeller performance

5.2.2 A60 motor performance

Figure 5.7,Figure 5.8,Figure 5.7,Figure 5.9,Figure 5.10 shows the performance of the A60 motor , The motor was tested with four different propeller sizes and pitch (19x15,21x14, 24x10 and 24x12). As we can see the figure the motor stalls at high air speeds which they are 25 and 30 m/s at 25 percent of throttle. In the other hand there is no stalling at 75 and 100 percent of throttle.

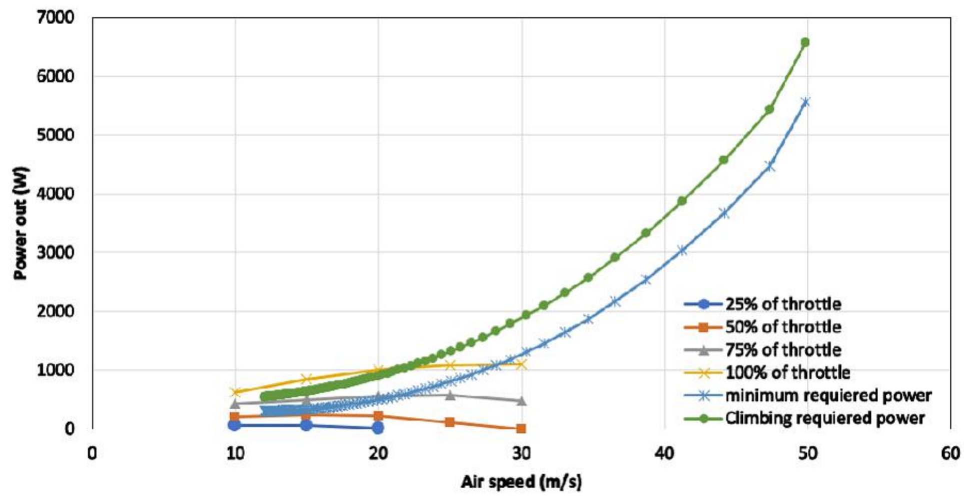


Figure 5.7: A60 with 19x15 propeller performance

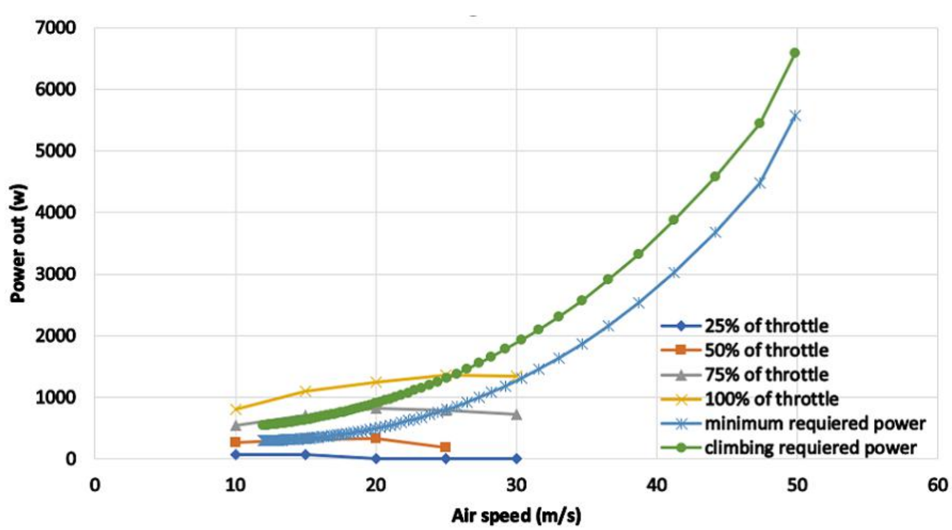


Figure 5.8: A60 with 21x14 propeller performance

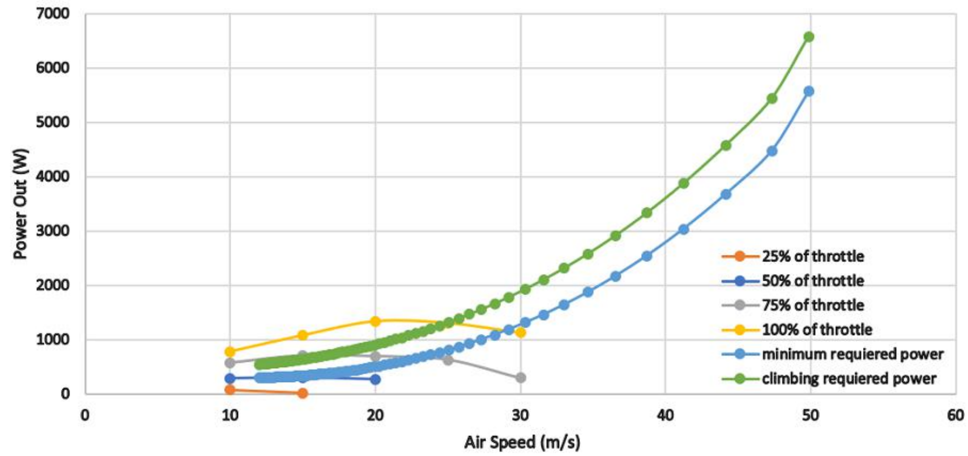


Figure 5.9: A60 with 24x10 propeller performance

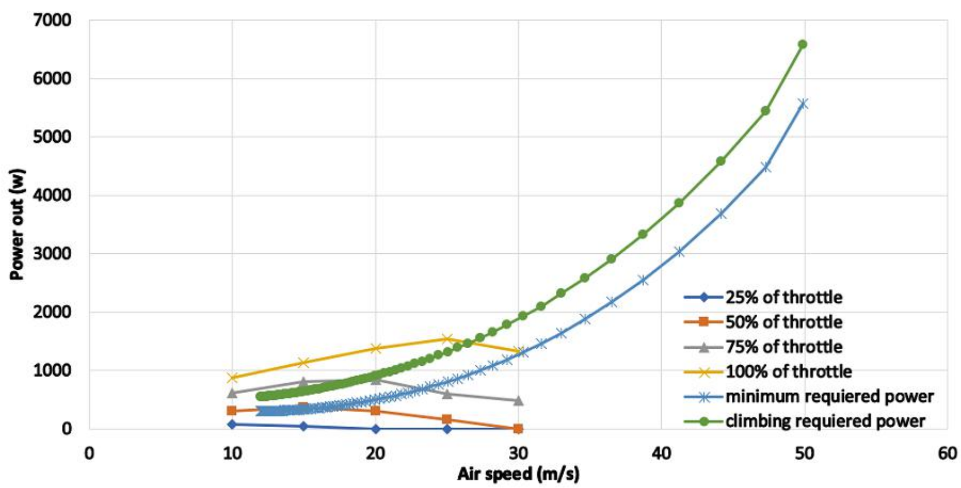


Figure 5.10: A60 with 24x12 propeller performance

5.2.3 Q80 motor performance

Figure 5.11,Figure 5.12 and Figure 5.13 shows the performance of the Q80 motor , The motor was tested with Three different propellers sizes and pitch (21x14, 22x12 and 24x12).

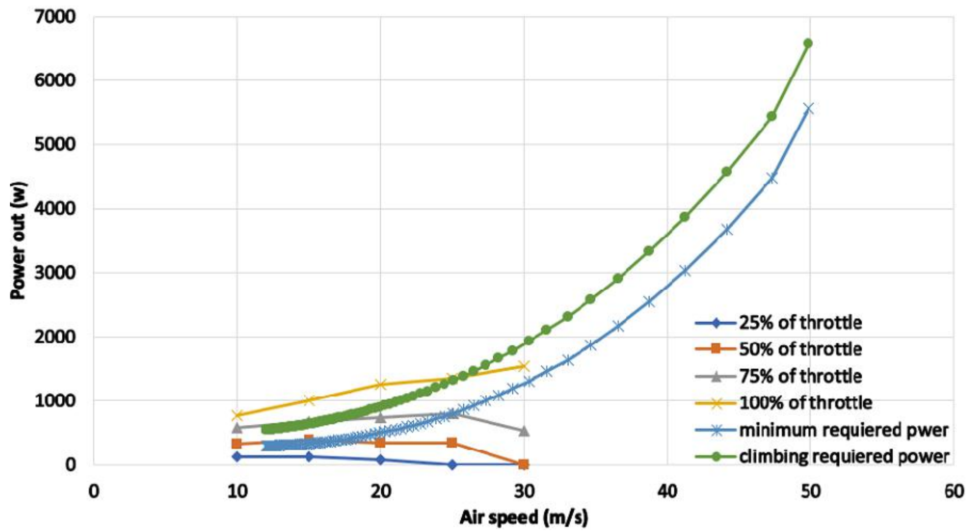


Figure 5.11: Q80 with 21x14 propeller performance

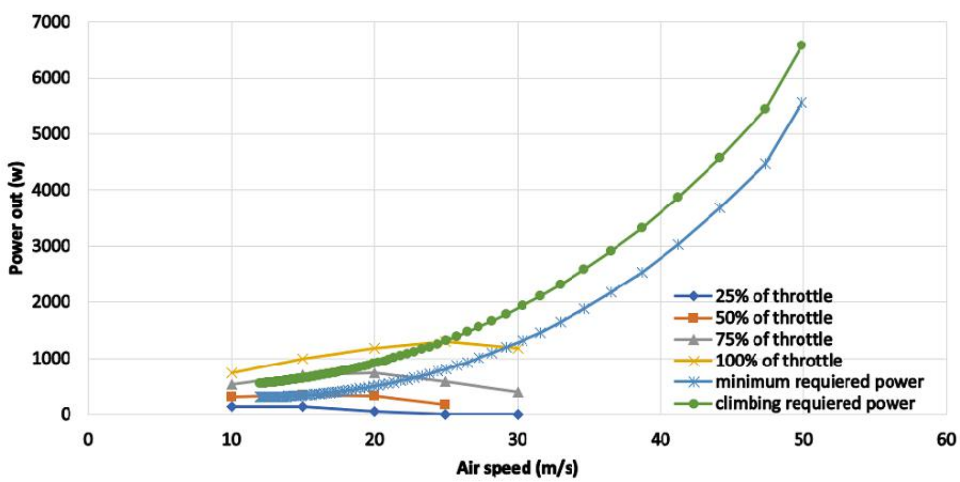


Figure 5.12: Q80 with 22x12 propeller performance

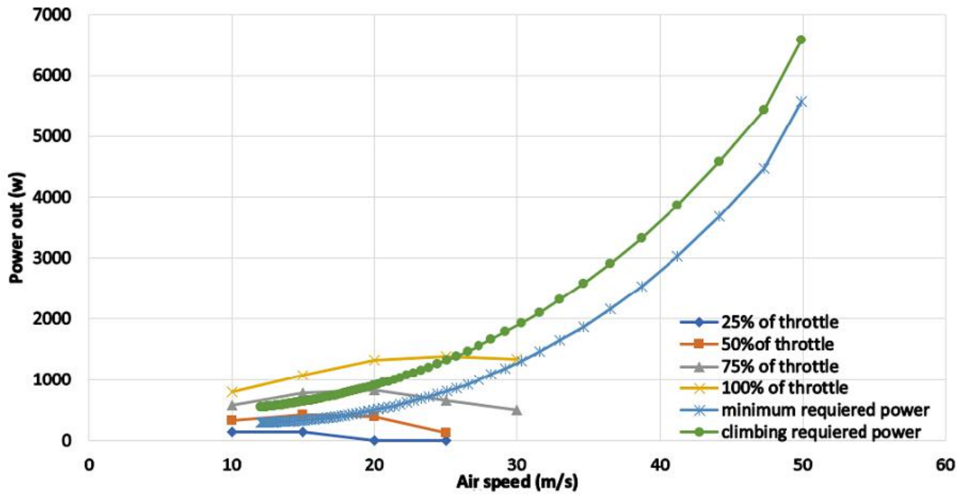


Figure 5.13: Q80 with 24x12 propeller performance

5.2.4 Data processing

In order to get the motor power curve and plot it against the theoretical curves , firs of all the output power of the motor is calculated as follows:

$$Wout = F(N).Airspeed$$

thus in the other hand the :

$$F = m(kg) \times a$$

the acceleration is 9.81 m/s2 , then we have the Wout. To calculate the efficiency:

$$n = \frac{Wattsin}{Wattsout}$$

After we get the output power for each throttle percentage we plot the $Wout$ vs. Air speed. Four motor curves for each motor propeller combination as we can see in figure 4.4 and figure 4.5 plotted vs the theoretical curves.

5.3 Evaluation

The aim of choosing the motor propeller combination is to select the combination that gives the bigger rang of manoeuvring so that the aircraft flies safely at the specific airspeed having a good amount of excess power for a safe flight. As it's shown in the figures above, its observed that the results or in other words the performance of the three motors are very close to each other. As it could be extracted from the results, the A50 motor is underpowered as shown in figure 5.4 , the A50 with (16x10) propeller stalls at 25 and 30 m/s with 25 percent of throttle, furthermore we can see that at 50 percent of throttle the aircraft burly flies as the actual power curve matches the required power as the power necessary for flying at 20m/s is 480 watts and the actual power out is 575.5 watts. The results are getting better with the bigger propellers but still not enough.

Obviously as in figure 5.5 and figure 5.6 the A60 and Q80 have more power and the most similar results, but finally, the most powerful combination will be chosen. The present results could be better with a bigger propeller which will be tested and implemented in future, but for now, this combination will be enough.

Chapter 6. Discussion

In this chapter, improvements, other choices and difficulties that was faced will be discussed along the all stages of the project.

6.1 Flight test and analysis

The best way to test the aircraft operation is to fly it and observe. As this power system was tested to be implemented on the aircraft, which still under construction, flight tests still needed to have the real performance data of the overall system. There are multiple parts and devices is using the same power source, It should be all work with harmony and without interference, some of them might be working properly and some maybe not. Hence an aircraft that not able to fly is difficult to troubleshoot. Also if its able to fly but not stable there will be a big risk for the aircraft to crash and to people also. The previous tests show that the aircraft can fly relying on the input data that we had and the output data.

6.2 Weight and power consumption

Tow main factors that play a big role in the designing of an aircraft is the power consumption and the weight. Considering the size of an aircraft, a bigger aircraft Will have a higher weight. A heavy aircraft demands a big amount of power to make it move and fly. In the other hand reducing size will reduce weight and power consumption but at the same time will limit the the the tasks that the drone will be able to do. A compensating between size and power consumption is the Ideal thing to do, To be able to do so the types of material used to build the aircraft should be selected carefully to be alight weight and durable. Nevertheless, The weights of the motors and other equipment should be taken into consideration. For this aircraft, the fuselage and the wings were built out from carbon fibre with a foam core. The carbon fibre is a lightweight, durable material that is ideal for building lightweight frames, using this kind of materials gives a possibility to build a larger size aircraft with no weight changes, so less power consumption.

6.3 Communication and control

Now a days, There are many advanced ways for controlling the aircraft and communicate with it. A Radio transmitter is the most used device to control the aircraft manually. Communication with auto pilot through mobile networks has more advantages than using WIFI network [13]. For this aircraft a radio transmitter and a receiver module system will be used to control and communicate with the auto pilot through the ground control station software provided with the auto pilot as mentioned in section (1.2 and 1.3)

6.4 Laws and restrictions

Drones are being used all over the world , Each country has its own regulations and laws regarding drones. Drone size and weight have different regulations across the countries. Depending on the type of operation that the drone will perform and the location, the regulation should be taken into consideration before designing or operating the drone. In Spain mainly as this project is built, developed in this country and it will be mainly used in this region, Spanish regulations should be not broken.

AESA circular of 6 April 2014, on the use of drones in Spain forbids the use of the drones for commercial or professional purposes. The Current regulation of law 18/2014, of 15 October, approving urgent measures for growth, competitiveness and efficiency has two articles about drones (art.50 and art.51). Article 50 is about everything related to drones, requirements to be a pilot, to be an operator, medical requirements and What I can do and What I can't do. Article 51 It defines a drone, it modifies the definition of aircraft of the law 48/1960 on air navigation because drones don't appear, So, art.51 modifies the definition to introduce the concept of drone in the concept of aircraft. Thanks for this point, drones exist, and they can fly.

This regulation was subsequently enacted into law and this process culminated on 17 October 2014 with the publication of law 18/2014 of 15 October approving urgent measures for growth, competitiveness and efficiency. It's interesting to look at what triggered the state to urgently regulate the use of drones via a royal Decree law. Never the fewer regulations still changing and new regulations are issued to push the drone's sector forward, in the 15th of December 2017 the Spanish Government approved the new regulation on drones. From now on it will be allowed to fly in urban areas and over crowds of people, upon approval of AESA (Spanish Aerospace Security Agency). The drone technology is constantly improving and is being implemented in different fields. That is why it is necessary to incorporate regulations to expand the number of environments where it is possible to fly UAVs. The recently approved regulation, which replaces the content of the Law 18/2014, allows more extensive and flexible operations, always guaranteeing the security of operations and promoting the growth of an emerging industry closely linked to R and D and tech innovation, according to “Ministerio de Fomento – Ministry of development”.

The past regulation established minimum requirements for operations with UAVs, but it did not cover all possible activities in which the industry has been raising and evolving. There are plenty of applications in audiovisual practices: using UAVs to record videos as they can carry even heavy cameras, for taking pictures and also recording action sports. It is also possible to incorporate auto-following flight, that follows a target at a specified distance with automatic flight. This aircraft is designed as a middle size aircraft with 25 kg of weight so no extra regulating is necessary as in Spain Drones until 150 kg is a competence of AESA. Drones from 25 to 150kg require an airworthiness certificate, a plate and operational authorisation. Drones Above 150kg is the competence of EASA, except drones for firefighting activities.

6.5 Ethics

Drones is used for various purposes, Civilian and commercial uses of drones for property management companies may include surveillance around malls or for monitoring and control of road traffic, domestic policing, oil, gas, and mineral exploration, and for the delivery of goods. Many of these uses of drones involve issues related to gathering data about individuals near a mall or in road traffic[14]. The same problems about privacy enter into the picture. These may both amount to an invasion of a person's right to privacy. An additional area of concern moving beyond this ethical problem is a situation where large numbers of drones are used for commercial purposes.

6.6 Safety

The down side of using drones regarding the safety that there is a risk of it falling and damaging properties and hurting people. Any malfunctioning of any of the drone system it might fall down, furthermore it is difficult to locate or predict where the falling object will hit. On the other hand , there is a risk of harming pilots flying manned air crafts since the drone doesn't have a pilot on bored or don't have a pilot at all, it will be difficult to take an immediate protection manoeuvre if a sudden object present. However, when the pilot is controlling the drone or its operating on autonomous mission with controlled conditions and in the visual line of sight , the safety will increase. Specially drones could operate in difficult to reach places and hazardous area will increase safety for the pilot.

6.7 Future attempts

Improvements always can be made as the technologies are getting more advanced day by day. To keep on competent in the market the systems and the hall aircraft should be upgraded to the latest technologies used in the market. Several systems will be improved, starting with the power system, solar energy will be used to charge up the batteries and have a longer flight time. Communication systems and control will be improved with more high quality and advanced systems. All parts of the system to be embedded in one mother bored such as ESCs, Sensors, and Autopilot to have the most efficient and compatible system that is easy to manufacture and implement in the aircraft. The airframe and the VTOL motors will have more compact design as the motors and propellers could be folded into the fuselage.

6.7.1 hydrogen power

This aircraft is running on batteries at present. In the near future, a hydrogen power system will be running the drone. Hydrogen power is more efficient and environmentally friendly. Using hydrogen for power systems is still under development many aspects need to be considered especially in safety as the hydrogen considered a high inflammable substance, many countries around the world still has many restrictions for using hydrogen.

Chapter 7. Conclusions

Power system optimisation for a fixed wing with VTOL capabilities was discussed in this thesis. Multiple propellers and motors combinations were tested statically and dynamically. The dynamic tests were done using a car and especial mounting on top of it because it was hard to afford a wind tunnel. Five different motors were tested with multiple propellers of different sizes and pitches. The batteries and ESC's were chosen to be compatible with the motor's current withdrawal, so all the system works in harmony and avoiding over heating elements. The batteries were selected carefully to give the ultimate performance and longer flight time.

After performing the tests, all of the motors performances were very close to each other, but the Q80 motor with 24x12 propeller was the best combination with the best results. The power system was not tested on the aircraft because its still under construction hence the results are promising. The most needful enhancement for the testing process is the way of collecting data, as in this thesis the data were collected on camera, in future its more convenient to have one system that manages all the parameters (Volts, Amperes, airspeed, power and rotation) synchronously in real time.

Drones sector is growing very fast day by day, new applications and new technologies are used by drones. The drones sector still under development especially in regulation and safety wise. More green energy will be used to power up the drones as solar energy hydrogen.

Appendix A. Appendix

	Percentage (%)	Air Speed (m/s)	Watts (in)	Amps	Thrust (g)	Corrected thrust(g)	Thrust (Kg)	Force (N)	Watts (out)	efficiency (%)
	25	10	327.5	8.14	1403	1626.64	1.62664	15.9573384	159.573384	48.7246974
		15	336.5	8.41	1150	1373.64	1.37364	13.4754084	202.131126	60.06868529
		20	305	7.7	774	997.64	0.99764	9.7868484	195.736968	64.17605508
		25			Stall					
		30								
	50	10	940.7	23.92	3594	3817.64	3.81764	37.4510484	374.510484	39.8118937
16x10 Plastic propeller		15	865.4	22.05	2954	3177.64	3.17764	31.1726484	467.589726	54.03163
		20	856.1	22.14	2710	2933.64	2.93364	28.7790084	575.580168	67.23281953
		25	822	21	1900	2123.64	2.12364	20.8329084	520.82271	63.36042701
		30	671	17.38	1350	1573.64	1.57364	15.4374084	463.122252	69.01970969
	75	10	1980	52.73	6292	6515.64	6.51564	63.9184284	639.184284	32.28203455
		15	2037.6	54.54	5655	5878.64	5.87864	57.6694584	865.041876	42.45395936
		20	1974	53.18	5193	5416.64	5.41664	53.1372384	1062.744768	53.83712097
		25	2000	56	4300	4523.64	4.52364	44.3769084	1109.42271	55.4711355
		30	1874	50.74	3891	4114.64	4.11464	40.3646184	1210.938552	64.61785229

	Percentage (%)	Air Speed (m/s)	Watts (in)	Amps	Thrust (g)	Corrected thrust(g)	Thrust (Kg)	Force (N)	Watts (out)	efficiency (%)
	25	10	385.6	10.01	1867	2090.64	2.09064	20.5091784	205.091784	53.18770332
		15	575	13.96	1780	2003.64	2.00364	19.6557084	294.835626	51.27576104
		20	482	11.82	873	1096.64	1.09664	10.7580384	215.160768	44.63916349
		25	583	14.37	715	938.64	0.93864	9.2080584	230.20146	39.48567067
		30	288	7.1	161	308.64	0.30864	3.0277584	90.832752	31.53915
	50	10	1236.7	33.11	4534	4757.64	4.75764	46.6724484	466.724484	37.73950708
18x12 Plastic Propeller		15	1481	37.48	4635	4858.64	4.85864	47.6632584	714.948876	48.27473842
		20	1649	41.15	4527	4750.64	4.75064	46.6037784	932.075568	56.52368514
		25	1337	33.98	3263	3486.64	3.48664	34.2039384	855.09846	63.95650411
		30	1244	31.69	2572	2795.64	2.79564	27.4252284	822.756852	66.13801061
	75	10	2009	56.44	6545	6768.64	6.76864	66.4003584	664.003584	33.05144769
		15	2136	55.71	6144	6367.64	6.36764	62.4665484	936.998226	43.86695815
		20	2002	52.26	5133	5356.64	5.35664	52.5486384	1050.972768	52.49614226
		25	2123	56.03	4940	5163.64	5.16364	50.6553084	1266.38271	59.65062223
		30	2331.2	62.25	4701	4924.64	4.92464	48.3107184	1449.321552	62.17062251

	Percentage (%)	Air Speed (m/s)	Watts (in)	Amps	Thrust (g)	Corrected thrust(g)	Thrust (Kg)	Force (N)	Watts (out)	efficiency (%)
	25	10	1187	30.34	2731	2954.64	2.95464	28.9850184	289.850184	24.41871811
		15	1263	32.64	1782	2005.64	2.00564	19.6753284	295.129926	23.3673734
		20	1069	28.01	1977	2200.64	2.20064	21.5882784	431.765568	40.3896696
		25	774	20.3	1375	1598.64	1.59864	15.6826584	392.06646	50.6545814
		30	555.2	14.67	199	346.5	0.3465	3.399165	101.97495	18.36724604
	50	10	1681	45.31	5921	6144.64	6.14464	60.2789184	602.789184	35.85896395
20x15 Plastic propeller		15	1655	44.35	4654	4877.64	4.87764	47.8496484	717.744726	43.36826139
		20	1889	52.4	5037	5260.64	5.26064	51.6068784	1032.137568	54.63936305
		25	1779	49.16	4176	4399.64	4.39964	43.1604684	1079.01171	60.65270995
		30	1629	45.16	3136	3359.64	3.35964	32.9580684	988.742052	60.69625856
	75	10	2049	56.8	6371	6594.64	6.59464	64.6934184	646.934184	31.57316662
		15	2132.6	59.39	6176	6399.64	6.39964	62.7804684	941.707026	44.15769605
		20	2142	59.87	5373	5596.64	5.59664	54.9030384	1098.060768	51.26334118
		25	2020	57.1	4529	4752.64	4.75264	46.6233984	1165.58496	57.70222574
		30	1909	54.39	3924	4147.64	4.14764	40.6883484	1220.650452	63.94187805

Figure A.1: A50 motor data

Propeller	Percentage (%)	Air Speed (m/s)	Watts (in)	Amps	Thrust (g)	Corrected thrust(g)	Volts	Thrust (Kg)	Force (N)	Watts (out)	efficiency (%)
19x15 wood propeller	25	10	151.8	3.35	650	878.5	45.34	0.65	6.3765	63.765	42.00592885
		15	137.5	3.02	395	542.5	45.53	0.395	3.87495	58.12425	42.27218182
		20	131	2.85	50	197.5	46.27	0.05	0.4905	9.81	7.488549618
		25	STALL								
		30									
	50	10	456.7	10.23	2012	2235.64	44.6	2.012	19.73772	197.3772	43.21813006
		15	435.7	9.74	1597	1820.64	44.74	1.597	15.66657	234.99855	53.93586183
		20	424.4	9.32	1160	1383.64	45.54	1.16	11.3796	227.592	53.6267672
		25	329.6	7.26	472	619	45.4	0.472	4.63032	115.758	35.12075243
		30	STALL								
	75	10	1013.5	23.57	4413	4636.64	43	4.413	43.29153	432.9153	42.71487913
		15	991.8	22.91	3339	3562.64	43.16	3.339	32.75559	491.33385	49.5396098
		20	965.1	21.92	2833	3056.64	44.03	2.833	27.79173	555.8346	57.59347218
		25	943.9	21.58	2346	2569.64	43.74	2.346	23.01426	575.3565	60.9552389
		30	834.7	19.02	1627	1850.64	43.86	1.627	15.96087	478.8261	57.36505331
	100	10	1778.8	43.75	6278	6501.64	40.66	6.278	61.58718	615.8718	34.62288059
		15	1801	44.39	5747	5970.64	40.59	5.747	56.37807	845.67105	46.95563853
		20	1853.3	44.92	5135	5358.64	41.26	5.135	50.37435	1007.487	54.36178708
		25	1773.3	43.2	4456	4679.64	43.74	4.456	43.71336	1092.834	61.62713585
		30	1717.7	41.37	3761	3984.64	41.4	3.761	36.89541	1106.8623	64.43862723

Propeller	Percentage (%)	Air Speed (m/s)	Watts (in)	Amps	Thrust (g)	Corrected thrust(g)	Volts	Thrust (Kg)	Force (N)	Watts (out)	efficiency (%)
21x14 Wood Propeller	25	10	190.8	4.12	742	970.5	46.33	0.742	7.27902	72.7902	38.15
		15	148.3	3.19	454	601.5	46.52	0.454	4.45374	66.8061	45.04794336
		20	STALL								
		25									
		30									
	50	10	616.7	13.47	2794	3017.64	45.18	2.794	27.40914	274.0914	44.44485163
		15	578	12.71	2155	2378.64	45.48	2.155	21.14055	317.10825	54.86301903
		20	556.6	11.97	1715	1938.64	46.5	1.715	16.82415	336.483	60.45328782
		25	387.9	8.35	752	980.5	46.46	0.752	7.37712	184.428	47.54524362
		30	STALL								
	75	10	1320.4	30.53	5530	5753.64	43.25	5.53	54.2493	542.493	41.08550439
		15	1307.3	30.02	4782	5005.64	43.55	4.782	46.91142	703.6713	53.82630613
		20	1406.1	32.03	4210	4433.64	43.9	4.21	41.3001	826.002	58.74418605
		25	1209.6	27.35	3223	3446.64	44.23	3.223	31.61763	790.44075	65.34728423
		30	1165.6	26.29	2463	2686.64	44.34	2.463	24.16203	724.8609	62.1877917
	100	10	2258.4	56.11	8234	9307.5	40.25	8.234	80.77554	807.7554	35.76671095
		15	2316.5	57.27	7524	7952.5	40.45	7.524	73.81044	1107.1566	47.79437082
		20	2217	55.05	6355	6578.64	40.29	6.355	62.34255	1246.851	56.24046008
		25	2204	53.06	5556	5779.64	41.35	5.556	54.50436	1362.609	61.82436479
		30	2106	51	4593	4816.64	41.31	4.593	45.05733	1351.7199	64.18423077

Propeller	Percentage (%)	Air Speed (m/s)	Watts (in)	Amps	Thrust (g)	Corrected thrust(g)	Volts	Thrust (Kg)	Force (N)	Watts (out)	efficiency (%)
24x10 wood propeller	25	10	174.6	3.6	730	953.64	48.52	0.73	7.1613	71.613	41.01546392
		15	141.7	2.93	129	352.64	48.38	0.129	1.26549	18.98235	13.39615385
		20	STALL								
		25									
		30									
	50	10	633.8	13.43	2914	3137.64	47.2	2.914	28.58634	285.8634	45.10309246
		15	555.7	11.76	2054	2277.64	47.26	2.054	20.14974	302.2461	54.39015656
		20	456.7	9.64	1355	1578.64	47.3	1.355	13.29255	265.851	58.21129845
		25	STALL								
		30									
	75	10	1360.6	30.4	5848	6071.64	44.73	5.848	57.36888	573.6888	42.16439806
		15	1275.8	28.34	4784	5007.64	45.02	4.784	46.93104	703.9656	55.17836652
		20	1180.2	25.94	3513	3736.64	45.5	3.513	34.46253	689.2506	58.40116929
		25	1030	22.65	2551	2774.64	45.51	2.551	25.02531	625.63275	60.74104369
		30	762	16.53	1016	1239.64	46.15	1.016	9.96696	299.0088	39.24
	100	10	2113.8	49.69	7932	8521.5	42.54	7.932	77.81292	778.1292	36.81186489
		15	2317.2	56	7334	7557.64	41.38	7.334	71.94654	1079.1981	46.57336872
		20	2350	55.6	6813	7036.64	42.22	6.813	66.83553	1336.7106	56.88130213
		25	2125	49.93	5315	5538.64	42.56	5.315	52.14015	1303.50375	61.34135294
		30	1844.6	42.85	3814	4037.64	43.05	3.814	37.41534	1122.4602	60.85114388

Propeller	Percentage (%)	Air Speed (m/s)	Watts (in)	Amps	Thrust (g)	Corrected thrust(g)	Volts	Thrust (Kg)	Force (N)	Watts (out)	efficiency (%)
24x12 wood propeller	25	10	191.2	4.16	843	1066.64	45.97	0.843	8.26983	82.6983	43.25224895
		15	157.1	3.3	311	534.64	47.62	0.311	3.05091	45.76365	29.13026735
		20	STALL								
		25									
		30									
	50	10	661	14.76	3074	3297.64	44.84	3.074	30.15594	301.5594	45.6216944
		15	659.2	14.25	2482	2705.64	46.26	2.482	24.34842	365.2263	55.40447512
		20	534.4	11.66	1579	1802.64	45.84	1.579	15.48999	309.7998	57.97151946
		25	373.6	8.15	612	835.64	45.05	0.612	6.00372	150.093	40.17478587
		30	STALL								
	75	10	1470.9	34.4	6301	6524.64	42.76	6.301	61.81281	618.1281	42.02380175
		15	1511	34.75	5539	5762.64	43.01	5.539	54.33759	815.06385	53.94201522
		20	1374.5	31.49	4305	4528.64	43.62	4.305	42.23205	844.641	61.4507821
		25	1085.8	24.64	2435	2658.64	44.07	2.435	23.88735	597.18375	54.99942439
		30	970.8	21.96	1651	1874.64	44.21	1.651	16.19631	485.8893	50.05040173
	100	10	2498.8	63.68	8913	9986.5	39.24	8.913	87.43653	874.3653	34.99140788
		15	2546.7	64.4	7688	8116.5	39.54	7.688	75.41928	1131.2892	44.42176935
		20	2413	60.72	6979	7202.64	39	6.979	68.46399	1369.2798	56.7459511
		25	2347.6	58.27	6257	6480.64	40.29	6.257	61.38117	1534.52925	65.36587366
		30	2132.8	51.83	4502	4725.64	41.15	4.502	44.16462	1324.9386	62.12202738

Figure A.2: A60 motor data

	Percentage (%)	Air Speed (m/s)	Watts (in)	Amps	Thrust (g)	Corrected thrust(g)	Volts	Thrust (Kg)	Force (N)	Watts (out)	efficiency (%)
21x14 wood propeller	25	10	273.6	5.79	1048	1271.64	47.26	1.27164	12.4747884	124.747884	45.59498684
		15	284.2	5.93	637	820.5	47.93	0.8205	8.049105	120.736575	42.48296094
		20	266.8	5.6	257	404.5	47.66	0.4045	3.968145	79.3629	29.74621439
		25	STALL								
		30									
	50	10	727.7	15.76	3145	3368.64	46.1	3.36864	33.0463584	330.463584	45.41206321
		15	741.6	15.86	2424	2647.64	46.76	2.64764	25.9733484	389.600226	52.53508981
		20	657.6	14.08	1573	1796.64	46.71	1.79664	17.6250384	352.500768	53.60413139
		25	599.9	12.83	1165	1388.64	46.76	1.38864	13.6225584	340.56396	56.77012169
		30	STALL								
	75	10	1509.1	34.16	5631	5854.64	44.1	5.85464	57.4340184	574.340184	38.05845762
		15	1410.5	31.62	4350	4573.64	44.6	4.57364	44.8674084	673.011126	47.71436554
		20	1392.5	31.2	3542	3765.64	44.56	3.76564	36.9409284	738.818568	53.05698873
		25	1323	29.4	3074	3297.64	45	3.29764	32.3498484	808.74621	61.12972109
		30	1079.1	23.76	1575	1798.64	45.42	1.79864	17.6446584	529.339752	49.05381818
	100	10	2432.1	58.48	7405	7833.5	41.59	7.8335	76.846635	768.46635	31.59682373
		15	2399.6	58.16	6592	6815.64	58.16	6.81564	66.8614284	1002.921426	41.79535864
		20	2376.7	57.27	6158	6381.64	41.5	6.38164	62.6038884	1252.077768	52.68135516
		25	2339.8	55.8	5315	5538.64	41.88	5.53864	54.3340584	1358.35146	58.05416959
		30	2198.3	52.07	5026	5249.64	42.22	5.24964	51.4989684	1544.969052	70.28017341

	Percentage (%)	Air Speed (m/s)	Watts (in)	Amps	Thrust (g)	Corrected thrust(g)	Volts	Thrust (Kg)	Force (N)	Watts (out)	efficiency (%)
22x12 wood propeller	25	10	265.2	5.77	1229	1452.64	45.97	1.45264	14.2503984	142.503984	53.73453394
		15	261.7	5.59	741	888.5	46.83	0.8885	8.716185	130.742775	49.95902751
		20	234.6	5.05	124	271.5	46.47	0.2715	2.663415	53.2683	22.70601023
		25	STALL								
		30									
	50	10	641.1	14.22	2921	3144.64	45.09	3.14464	30.8489184	308.489184	48.11873093
		15	590.9	12.87	2114	2337.64	45.92	2.33764	22.9322484	343.983726	58.21352615
		20	554.3	21.14	1453	1676.64	45.66	1.67664	16.4478384	328.956768	59.34634097
		25	474.1	10.42	435	658.64	45.5	0.65864	6.4612584	161.53146	34.07117908
		30	STALL								
	75	10	1265.4	29.09	5177	5400.64	43.5	5.40064	52.9802784	529.802784	41.86840398
		15	1293.1	29.25	4499	4722.64	44.21	4.72264	46.3290984	694.936476	53.74189746
		20	1187.3	26.85	3510	3733.64	44.22	3.73364	36.6270084	732.540168	61.69798433
		25	1063	24.1	2155	2378.64	44.11	2.37864	23.3344584	583.36146	54.87878269
		30	993.6	22.33	1131	1354.64	44.5	1.35464	13.2890184	398.670552	40.12384783
	100	10	2157.4	52.75	7343	7566.64	40.95	7.56664	74.2287384	742.287384	34.40657198
		15	2232	53.68	6571	6794.64	41.58	6.79464	66.6554184	999.831276	44.79530806
		20	2133.9	51.57	5755	5978.64	41.38	5.97864	58.6504584	1173.009168	54.97020329
		25	2024	48.81	5066	5289.64	41.48	5.28964	51.8913684	1297.28421	64.09506966
		30	1911.1	45.46	3764	3987.64	42.04	3.98764	39.1187484	1173.562452	61.40769463

	Percentage (%)	Air Speed (m/s)	Watts (in)	Amps	Thrust (g)	Corrected thrust(g)	Volts	Thrust (Kg)	Force (N)	Watts (out)	efficiency (%)
24x12 wood propeller	25	10	245.7	5.47	1176	1399.64	44.93	1.39964	13.7304684	137.304684	55.88306227
		15	260.2	5.7	855	1002.5	45.65	1.0025	9.834525	147.517875	56.69403344
		20	STALL								
		25									
		30									
	50	10	694.4	15.84	3101	3324.64	43.84	3.32464	32.6147184	326.147184	46.96820046
		15	687.5	15.41	2674	2897.64	44.62	2.89764	28.4258484	426.387726	62.02003287
		20	622.8	13.99	1774	1997.64	44.52	1.99764	19.5968484	391.936968	62.93143353
		25	475.5	10.72	375	522.5	44.36	0.5225	5.125725	128.143125	26.94913249
		30	STALL								
	75	10	1324.8	31.29	5609	5832.64	42.34	5.83264	57.2181984	572.181984	43.19006522
		15	1416.1	33.11	5069	5292.64	42.77	5.29264	51.9207984	778.811976	54.9969618
		20	1329	31.09	3972	4195.64	42.75	4.19564	41.1592284	823.184568	61.94014808
		25	1153.5	26.97	2457	2680.64	42.77	2.68064	26.2970784	657.42696	56.99410143
		30	1005.7	23.39	1457	1680.64	43	1.68064	16.4870784	494.612352	49.18090405
	100	10	2187	55.2	7676	8104.5	39.62	8.1045	79.505145	795.05145	36.35351852
		15	2389	61.07	7115	7338.64	39.12	7.33864	71.9920584	1079.880876	45.20221331
		20	2347.8	59.23	6520	6743.64	39.64	6.74364	66.1551084	1323.102168	56.35497777
		25	2268	56.66	5444	5667.64	40.03	5.66764	55.5995484	1389.98871	61.28698016
		30	2072	51.53	4353	4576.64	40.21	4.57664	44.8968384	1346.905152	65.0050749

Figure A.3: Q80 motor data

Bibliography

[1] Rune Yding Brogaard, *Drone inspection of offshore oil & gas constructions*,Force Technologies, Retrieved from (`https/forcetechnology.com/en/services/drone-inspection-offshore-oil-gasconstructions`, accessed at Aug,2018.

[2] Chris Anderson, *Agricultural drones*, MIT Technology review,June 2014, Retrieved from (`https://www.technologyreview.com/s/526491/agricultural-drones/`), accessed at Aug,2018.

[3] Kevin Gallagher, *How drones are changing inspections in the utility industry*, Simulize (02 may 2017), Retrieved from (`https://www.simulyze.com/blog/how-drones-are-changing-inspections-in-the-utility-industry`), accessed at Aug,2018.

[4] KDE Direct ,*Developing the future of drones in mining* ,KDE direct news release,Feb 2016. Retrieved from (`https://www.kdedirect.com/blogs/news/88752963-developing-the-future-of-drones-in-mining`), accessed at Aug,2018.

[5] Dynamic Flight,*Aerofoil in general*, Dynamic flight, Nov 2017, retrieved from (`http://www.dynamicflight.com/aerodynamics/airfoils/`), accessed on Aug 2018.

[6] Micro Pilot, *MP2128 UAV autopilot*, retrieved from (`http://store.micropilot.com/product-p/a-2128-helig2.htm`), accessed at Aug 2018

[7] Ground Control Station,*HORIZON ground control station*,retrieved from (`http://store.micropilot.com/HORIZON-sup-mp-sup-GCS-p/g-horiz.htm`), accessed at Aug 2018.

[8] National renewable energy laboratory and the department of energy.*Hydrogen Energy*, Renewable energy world, retrieved from (`https://www.renewableenergyworld.com/hydrogen/tech.html`), accessed at Aug 218.

[9] Solar energy usa team,*Batteries*, solar energy usa, retrieved from (`http://solarjourneyusa.com/batteries.php`), accessed at Aug 2018.

[10] Tarun Agarwal, *Introduction to electronic speed control (ESC) working and applications*, elprocus, retrieved from (`https://www.elprocus.com/electronic-speed-control-esc-working-applications/`), accessed at Aug 2018.

[11] Michał Mazur et al,*Experimental characterization of brushless DC motors and propellers for flight application*,Proceedings of The Canadian Society for Mechanical Engineering International Congress 2016 ,June 26-29, 2016, Kelowna, BC, Canada.

[12] Chris Woodford, *Propellers*, Explainthatstuff, July 16, 2018, retrieved from (https://www.explainthatstuff.com/how-propellers-work.html), accessed at Aug 2018.

[13] Mario G. C. A. Cimino, Nedo Celandroni, Erina Ferro, Davide La Rosa, Filippo Palumbo, Gigliola Vaglini, *Wireless communication, identification and sensing technologies enabling integrated logistics: a study in the harbor environment*, in the framework of the PRIN project by Italian MIUR(Ministry for Education, University and Research), Oct 21, 2015

[14] Richard L. Wilson, *Ethical issues with use of drone aircraft*, University of Maryland at Baltimore County Philosophy/Engineering Management.